COMMUNITY ASSISTANCE PLANNING REPORT NO. 262
(2ND EDITION)

A LAKE MANAGEMENT PLAN FOR NAGAWICKA LAKE

WAUKESHA COUNTY, WISCONSIN

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

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A LAKE MANAGEMENT PLAN FOR NAGAWICKA LAKE

EXECUTIVE SUMMARY

A Management Plan for Nagawicka Lake and its Watershed

The health of a lake ecosystem is usually a direct reflection of the use and management of the land within its watershed. While Nagawicka Lake (the Lake) is generally healthy, high rates of phosphorus and sediment loading have and will continue to harm the Lake if active management action is not taken. The Nagawicka Lake Management Plan (the Plan) is the second comprehensive management plan for this Lake and was developed to provide a set of targeted, specific recommendations to improve Nagawicka Lake, the Bark River (the River), and ecological conditions throughout the watershed. This Plan supplements and builds upon previous plans and recommendations, such as the 2006 and 2012 aquatic plant management plan updates (see sewrpc.org), as well as studies by the Wisconsin Department of Natural Resources (WDNR) and the U.S. Geological Survey (USGS).

Characteristics of Nagawicka Lake and its Watershed

Nagawicka Lake is a high-quality lake and a premier recreational destination. The Lake, one of the largest and deepest in Southeastern Wisconsin, has hard water, good water clarity, a diverse aquatic plant community, and a healthy sport and panfish fishery. Classified as one of the few two-story lakes in the Region, the Lake could potentially again host this rare ecosystem that would support an even more outstanding sport fishery (e.g., larger, faster growing walleye and northern pike). Located in the metropolitan Milwaukee area, its visitors and residents engage in a wide variety of recreational pursuits including fishing, swimming, sailing, water-skiing, and other activities. The Lake's largest tributary is the Bark River, supplying nearly three-quarters of its water, while precipitation, groundwater, and other tributaries supply the rest. The Lake is fed by a 44.6 square mile watershed located primarily within Waukesha County, with the most upstream area draining a small portion of Washington County. Agricultural and residential land uses are the most common land uses within the watershed.

Boating, sailing, fishing, and swimming are popular recreational activities on Nagawicka Lake

Justification for Plan

While the Lake enjoys generally good water quality and conditions supporting a wide variety of use, issues of concern exist that justify further study. These issues of concern addressed in this management plan include the following:

- Water Quality Trends
- Sediment Loading and Accumulation
- Priority Areas for Pollutant Load Reduction
- Aquatic Plant Management
- Restoring Natural Hydrology in a Changed Landscape

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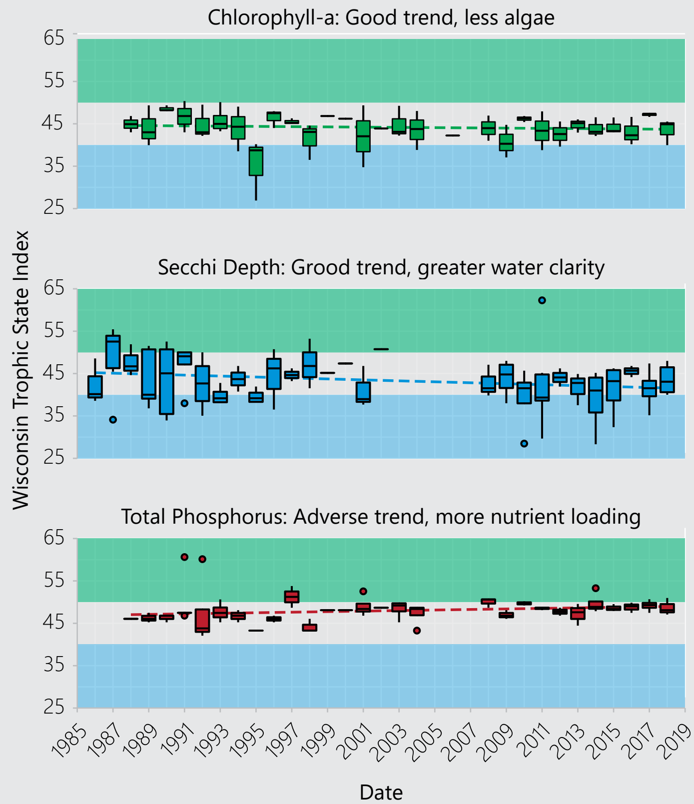
Water Quality Trends

Nagawicka Lake has maintained its mesotrophic status for decades, with recent improvements in water clarity, algae reduction, and oxygen concentrations. In the 1970s, the Lake was hypereutrophic, but the water quality substantially increased after diversion of sewage effluent in 1980. Since the late 1980s, water clarity has increased and chlorophyll-*a* concentrations, an indication of algal abundance, has decreased. Additionally, the extent of summertime anoxic (no oxygen) water near the lake bottom has substantially decreased, providing more suitable habitat for aquatic organisms and reducing phosphorus release from sediment. However, total phosphorus concentrations have increased since 1980. If this trend continues, excessive phosphorus will decrease water clarity, fuel excessive growth of algae and aquatic plants, and may impair the Lake's ability to support its current recreational uses. These insights are only possible thanks to the 35 years of consistent water quality monitoring on the Lake, much of which has been conducted by volunteers.



Source: Wisconsin Department of Natural Resources and SEWRPC

Greater water clarity and reduced algal abundance indicate improving water quality. Increasing phosphorus remains an issue of concern.

35 years of water quality monitoring on Nagawicka Lake provides invaluable insight. Continued monitoring is essential to track future water quality change.

Increasing phosphorus and sediment loading threaten environmental quality and/or recreational use within the Lake if unaddressed. The U.S. Environmental Protection Agency (USEPA) and the Wisconsin Department of Natural Resources (WDNR) have identified the Bark River watershed as a significant contributor of phosphorus and sediment to the Rock River, with reaches of the River listed as impaired for low dissolved oxygen. The USEPA established a total maximum daily load (TMDL) in 2011 for the Rock River basin to address excessive phosphorus and sediment pollution. Since the Bark River watershed is part of Rock River TMDL, these state-permitted allocations establish a minimum standard of phosphorus and sediment reduction goals in the Lake watershed. These goals are as follows:

Pollutant	Nonpoint Source Pollution Sources	Non-Permitted Urban Sources	MS4 Systems	Wastewater Treatment Plants
Total Phosphorus	46% (445 lbs)	8% (73 lbs)	68% (894 lbs)	79% (1,786 lbs)
Total Suspended Solids	35% (58 yd^3)	4% (7.5 yd^3)	43% (114 yd^3)	28% (9 yd^3)

The recommendations provided within this management plan will help communities reduce their pollutant loading to meet and exceed these goals.

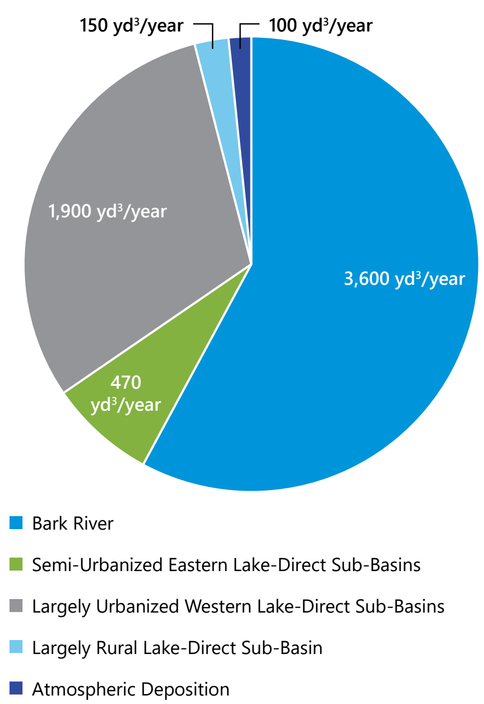
Sediment Loading and Accumulation

Sedimentation has been a long-time concern of Lake residents. The Commission evaluated sediment depths within the Lake, as well as sediment accumulations along the Bark River. Sediment was scarcely present in the River below the Merton millpond, but thick sediment deposits were found close to the River's inlet to the Lake. Sediment accumulation in the Lake was most pronounced at the mouth of the River, where an "island" of sediment has become a navigational and safety concern for Lake residents. The River is the single largest contributor of externally sourced sediment to the Lake. Available data suggests it delivers 3,600 cubic yards of sediment each year, predominantly in large pulses after heavy rainfall. Lake-direct urbanized and semiurbanized tributaries contribute more sediment per acre then those draining into the Bark River, collectively contributing 2,370 cubic yards of sediment each year. A rural Lake-direct tributary contributes an additional 150 cubic yards per year while atmospheric deposition contributes 100 cubic yards per year.

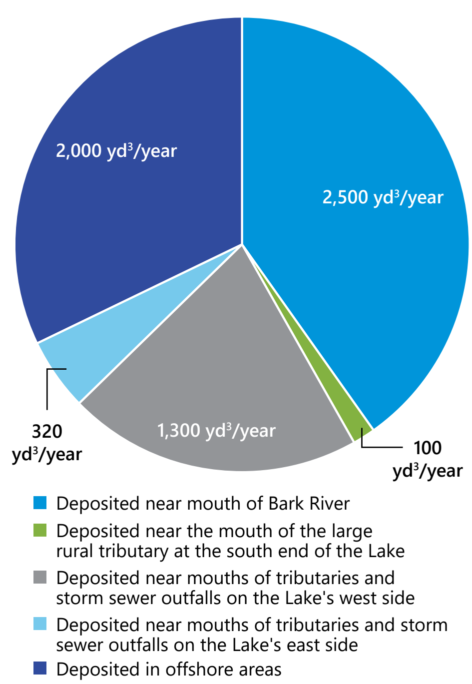
Sediment accumulation at the mouth of the Bark River on Nagawicka Lake is an important issue of concern.

Sediment is not uniformly deposited throughout the Lake. The Bark River delta accumulates the largest amount of externally sourced sediment, with an estimated sediment deposition rate of roughly 2,500 cubic yards per year. Portions of the Lake near the mouths of Lake-direct tributaries accumulate about 1,720 cubic yards of externally sourced sediment per year. The remainder of the externally sourced sediment (about 2,000 cubic yards) is likely deposited in offshore areas. Management recommendations to address sediment loading and accumulation are provided in greater detail in the Plan.

Nagawicka Lake External Sediment Sources



Fate of Nagawicka Lake External Sediment Sources



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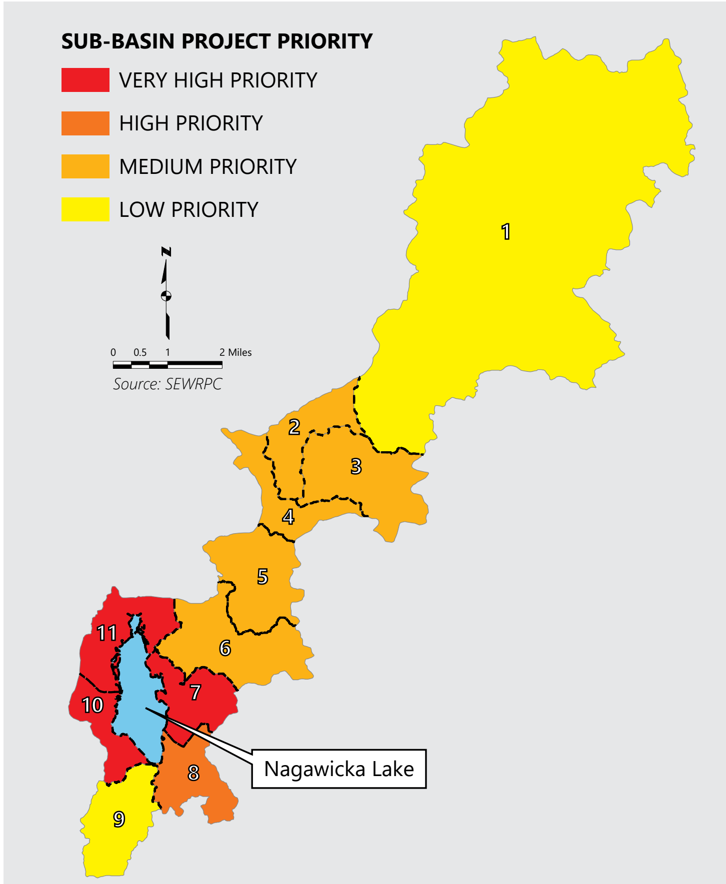
Priority Areas for Pollutant Load Reduction

This planning project identifies priority areas for pollutant load reduction to the Lake. In this regard, the Commission performed field inventories of the Bark River and Lake shoreline conditions, examined previous studies, and conducted pollutant load modeling throughout the watershed. The majority of the Bark River was in good condition, with ample connection to adjacent floodplain, extensive vegetation buffers, and few instances of bank erosion. In contrast, the Lake shoreline exhibited several instances of shoreline erosion and most of the shoreline lacked vegetative buffers. A previous USGS study noted that basins with direct drainage to the Lake contributed more phosphorus per acre than the upstream Bark River basin. Commission pollutant load modeling, which indicated that basins adjacent to the Lake had the highest phosphorus and sediment loading per acre, supported the USGS findings.



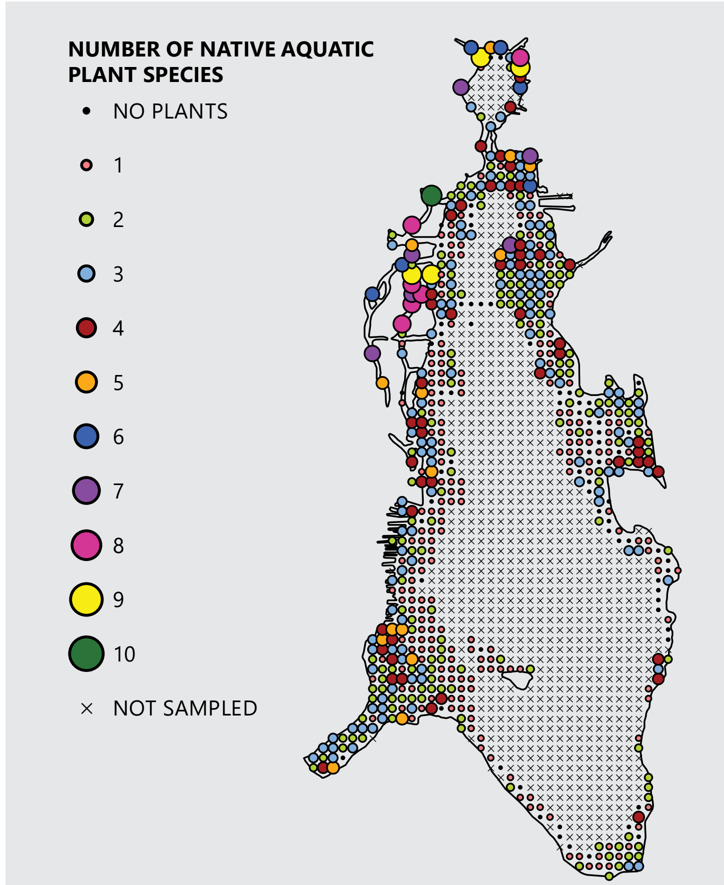
Sub-basins of the Nagawicka Lake watershed were prioritized by their potential to reduce phosphorus and sediment loading.

Achieving the phosphorus and sediment reduction goals set by the TMDL will require major commitments from all watershed stakeholders to implement best management practices. These practices include creating shoreline and riparian buffers, installing rain gardens, using cover crop and no-till practices, and retrofitting existing stormwater infrastructure. Sub-basins with direct drainage to the Lake should be prioritized, as management practices here will be the most effective at reducing pollutant loading to the Lake. A comprehensive inventory of priority areas and parcels for riparian and shoreline buffers as well as storm drainage systems is provided in the Plan.

The shoreline of Nagawicka Lake has many opportunities for vegetated buffers to reduce phosphorus and sediment loading as well as protect the shoreline from erosion. Deep-rooted native vegetation stabilizes shorelines and helps remove phosphorus and sediment from runoff.

Aquatic Plant Management

Dedicated aquatic plant management in Nagawicka Lake has supported a healthy aquatic plant community and removed substantial amounts of total phosphorus from the Lake. The aquatic plant community of Nagawicka Lake is very diverse with 32 species identified in a 2016 survey, including many beneficial native species. Muskgrass (*Chara* spp.), the most dominant species, is a native that stabilizes lake bottom sediment and removes phosphorus from the water column; this species should be a priority for protection. Invasive species, such as Eurasian watermilfoil and Curly-leaf pondweed, are present in the Lake but are not widespread, covering less than 3 percent of the Lake. Since 2003, the aquatic plant harvesting program operated by the City of Delafield has removed up to a cumulative 12,346 lbs. of total phosphorus from the Lake. This phosphorus removal, as well as nurturing a healthy native plant community, contributes to water quality improvements. The Plan provides detailed aquatic plant management recommendations, including measures to maintain navigational lanes within sensitive areas.



Nagawicka Lake has a healthy native aquatic plant community. Species richness within the Lake is highest along the northwestern shore and the northern kettle.

Phosphorus Removal by Harvesting:
The City of Delafield has removed up to 12,346 lbs. of phosphorus through aquatic plant harvesting since 2003.

Restoring Natural Hydrology in a Changed Landscape

The Nagawicka Lake watershed has been dramatically altered from pre-settlement conditions when upland hardwood forest covered the northern portion and the southern portion supported oak savannah and wetlands. The watershed is now mostly occupied by agricultural and residential land uses, with urban development expected to comprise 59 percent of the watershed by 2050. Land conversion has changed the hydrology of the watershed through stream channelization, dam construction, filling of wetlands, and increasingly through cover by impervious surface (e.g., buildings, roads, parking lots). These hydrologic changes reduce the landscape's ability to capture, filter, and retain precipitation; maintain streamflow during dry periods; and provide suitable habitat for many fish species. Additionally, public sewers, which export water out of the Lake's watershed and ultimately reduce the volume of groundwater discharged to the Lake and its tributaries, service or plan to service at least one-third of the watershed. The recommendations in this Plan will help communities preserve the Lake's water supply by modulating floodwater volumes, protecting groundwater infiltration, and limiting water exports from the watershed.

Key Management Objectives to Improve the Nagawicka Lake Watershed

- Use existing TMDL guidance for phosphorus and sediment load reduction goals
- Continue water quality monitoring to track progress toward meeting nonpoint source load reductions and improving water quality
- Prioritize implementation of buffers, rain gardens, and other best management practices (BMPs) in sub basins adjacent to Lake and especially along shoreline
- Promote native aquatic plant species and remove phosphorus through discerning aquatic plant harvesting
- Preserve or enhance groundwater infiltration and limit water exports from the watershed
- Establish partnerships between municipalities, associations, and permitted entities to collaborate on water quality goals and pursue funding

Funding and Partnerships

Fortunately, funding may be available to implement BMPs within the Nagawicka Lake watershed. For example, interested Lake shoreline owners can apply by contacting the Lake Welfare Committee (LWC) to receive funding for implementing the BMPs recommended in the Healthy Lakes Program, including fish sticks, rain gardens, native vegetation buffers, diversions, and rock infiltrations. Implementing the Healthy Lake BMPs on at least 75 percent of the shoreline properties would substantially reduce pollutant loading into the Lake while improving habitat for fish and wildlife. Several federal and state funding sources also exist to promote conservation practices and protect water quality. The Natural Resource Conservation Service (NRCS) provides several programs, such as the Conservation Reserve Program, to implement BMPs and promote land conservation in agricultural lands. The Wisconsin Department of Agriculture, Trade and Consumer Protection offers grant funding for farmer-led activities to reduce nonpoint source pollution. Local land trusts work with landowners to preserve land through conservation easements, land purchases, and land donations.

Native vegetation buffer implemented on Nagawicka Lake with funding from the Healthy Lakes Program.

The greatest potential for funding projects within the Lake's watershed may be through the establishment of an "Adaptive Management Program" to address permitted phosphorus point source loads. Adaptive management is a phosphorus compliance option that allows point and nonpoint sources to work together to reduce watershed phosphorus loading. As an example, the City of Oconomowoc established a program with the City of Oconomowoc Wastewater Utility and other partners to reduce pollutant loading in the Oconomowoc River watershed for the Rock River TMDL. Establishment of a similar program between the Dela-Hart wastewater treatment facility and the municipalities within the Bark River watershed should be considered, as this would enable greater opportunities for cost-sharing and achieving TMDL compliance.

Investing in the watershed, such as helping farmers purchase equipment for cover crops and retrofitting stormwater systems, is the best long term solution to protect Nagawicka Lake.

Partnership and Collaboration Necessary to Achieve Water Quality Goals

The Nagawicka Lake watershed currently embodies significant and unique aesthetic and ecological values and has the potential to be a more diverse and resilient aquatic ecosystem. Water quality within the Lake has slightly improved since 1980, but phosphorus and sediment loading as well as long-term depletion of groundwater resources remain major challenges. Following the recommendations provided in this Plan will lead to improved water quality and quantity for human needs and will help improve the hydrological and ecological integrity of the water resources. This will also lead to a healthier and more resilient local economy.

Meeting the goals for the Nagawicka Lake watershed will continue to be a challenge requiring the collaboration of many participating organizations adopting the efforts of a unified plan. The measures presented in this Plan primarily focus on those that can be implemented through collaboration between local organizations and individuals, such as the LWC; Lake residents; Waukesha County; the WDNR; the Dela-Hart wastewater treatment facility; the City of Delafield; the Villages of Chenequa, Hartland, Merton, Nashotah, Richfield, and Sussex; and the Towns of Delafield, Lisbon, and Merton. The plan must be adaptable to address challenges that will arise during implementation. Watershed implementation is primarily a volunteer effort, but this effort needs support through targeted technical and financial assistance. All communities within the watershed must commit and collaborate to reach compliance with existing regulations, which in turn help improve the Lake's condition.

You Can Help Protect Nagawicka Lake

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INTRODUCTION 1

Credit: SEWRPC Staff

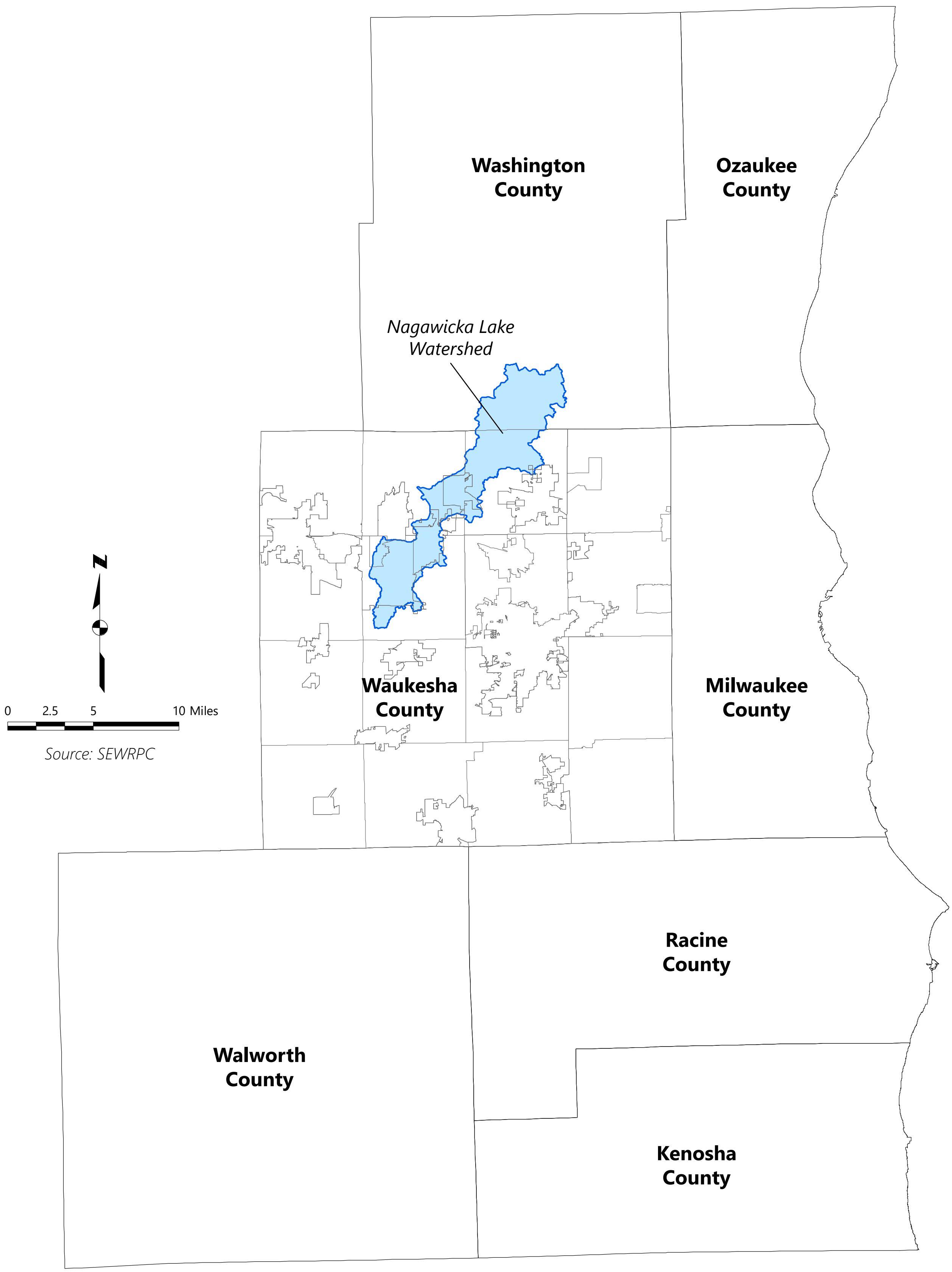
Nagawicka Lake lies within U.S. Public Land Survey Sections 5, 8, 9, 16, 17, 20, and 21, Township 7 North, Range 18 East in north-central Waukesha County, Wisconsin. The Lake is located partially in the City of Delafield and partially in the Village of Nashotah and is on the fringe of metropolitan Milwaukee (see Map 1.1). Nagawicka Lake, together with its associated watershed and wetlands, is an important high-quality natural resource and is a substantial asset to the local and regional community. For this reason, preserving and enhancing the Lake's health is an issue of considerable interest to resource managers, Lake residents, Lake users, and others who benefit from the Lake's recreational, ecological, and aesthetic value.

1.1 PLAN PURPOSE AND OVERVIEW

The health of a lake or stream is usually a direct reflection of land use and management within its watershed. Intervention is often necessary to maintain or improve lake and watershed conditions. This plan provides a framework to protect and improve the land and water resources of Nagawicka Lake and its watershed with a focus on protecting this high-quality resource from undesirable human influence thus preventing future degradation.

The plan is divided into three chapters. Chapter One briefly outlines the plan's purpose, summarizes basic Lake characteristics and assets, and presents the study's general goals and objectives. Chapter Two presents and interprets information needed to understand Lake conditions and the factors that could imperil Lake health. Finally, Chapter Three discusses approaches to protect and enhance the Lake and its watershed. Chapter Three recommendations aim to enhance and preserve Nagawicka Lake's native plant community, ecology, and water quality yet allow activities that continue to allow lake users and watershed residents with comfortable modern lifestyles and opportunities for safe and enjoyable recreation within the Lake and the Lake's watershed.

Map 1.1
Location of the Nagawicka Lake Watershed



Source: SEWRPC

This plan complements existing plans,[1] programs, and ongoing management actions in the Nagawicka Lake watershed. The plan represents the continuing commitment of government agencies, municipalities, and citizens to diligent lake planning and natural resource protection. Additionally, this plan was designed to assist State agencies, local units of government, nongovernmental organizations, businesses, and citizens develop strategies that benefit the natural assets of Nagawicka Lake and its watershed. By using the strategies outlined in this plan, results will be achieved that enrich, preserve, and increase ecological resilience, and help assure long-term sustainability of the natural environment.

This planning program was funded in part by a Chapter NR 190 Lake Management Planning grant awarded to the City of Delafield Lake Welfare Committee (LWC), which is a cooperative effort between the City of Delafield and the Village of Nashotah. Examples of major grant program deliverables include the following items:

- An updated aquatic plant inventory and management plan
- An assessment of Lake water quality condition and trends
- A field inventory mapping locations of streambank erosion and nonpoint pollution sources on the Bark River upstream of the Lake and on the Lake itself
- A field investigation allowing sediment depths to be estimated in the Lake and suggestions for controlling sedimentation
- Maps delineating the watershed and defining characteristics such as groundwater recharge potential, buffers, and existing/planned land use
- Estimated sediment and nutrient loads derived from several simulation models
- Specific recommendations for watershed management including maps and an action plan
- Establishing load reduction goals consistent with the Rock River basin Total Maximum Daily Load (TMDL) allocations
- A comprehensive written report

The inventory and aquatic plant management plan elements presented in this report conform to requirements and standards set forth in relevant Wisconsin Administrative Codes.[2]

1.2 CHARACTERISTICS AND ASSETS OF NAGAWICKA LAKE AND ITS WATERSHED

Nagawicka Lake is classified by the Wisconsin Department of Natural Resources (WDNR) as a drainage lake. The Lake is essentially a wide and deep section of the Bark River. The River enters the Lake on the northeastern shore and exits the Lake's southwestern embayment. Nagawicka Lake is located in the central portion of the Bark River watershed, downstream of Bark Lake, and upstream of a chain of lakes that include Upper and Lower Nemahbin Lakes and Crooked Lake. The Bark River enters the Rock River near Fort Atkinson, Wisconsin. From there, the Rock River enters the Mississippi River just south of Rock Island, Illinois. Water from Nagawicka Lake and the Bark River watershed ultimately discharges to the Gulf of Mexico.

[1] *SEWRPC Memorandum Report No. 130,* A Lake and Watershed Inventory for Nagawicka Lake, Waukesha County, Wisconsin*, March 1999; SEWRPC Community Assistance Planning Report No. 262,* A Lake Management Plan for Nagawicka Lake, Waukesha County, Wisconsin*, March 2001; and SEWRPC Memorandum Report No. 161,* An Aquatic Plant Management Plan for Nagawicka Lake, Waukesha County, Wisconsin*, March 2006.*

[2] *This plan has been prepared pursuant to the standards and requirements set forth in the following chapters of the* Wisconsin Administrative Code*: Chapter NR 1, "Public Access Policy for Waterways;" Chapter NR 40, "Invasive Species Identification, Classification and Control;" Chapter NR 103, "Water Quality Standards for Wetlands;" Chapter NR 107, "Aquatic Plant Management;" and Chapter NR 109, "Aquatic Plants Introduction, Manual Removal and Mechanical Control Regulations."*

Based upon WDNR records, Nagawicka Lake is one of Waukesha County's largest lakes. The Lake is also the second deepest in Waukesha County and the fourth deepest in all of Southeastern Wisconsin.[3] The Lake and its watershed cover over 46 square miles in Waukesha and Washington Counties. Chapter Two provides more detail regarding the morphometry, morphology, and hydrology of Nagawicka Lake and the Bark River, and relates these characteristics to water quality, aquatic plants, fisheries, recreation, and overall Lake management.

Nagawicka Lake and its watershed provide numerous, widely varying, recreational assets. Prominent features include Naga-Waukee County Park, the Lake Country Trail, several public boat launches and marinas, campgrounds, and large number of shoreline residences. The Lake successfully supports a spectrum of recreational interests as evidenced by boat counts and observations completed by Southeastern Wisconsin Regional Planning Commission staff during summer 2016 (see Chapter Two for more details). Lake users engage in full-body contact uses (such as swimming and water skiing) as well as pleasure cruising, high-speed boating, fishing, and other activities.

Nagawicka Lake supports a healthy fishery with a wide range of sport and panfish. Nagawicka Lake is one of only a few lakes in Southeastern Wisconsin that hosts or once hosted a naturally occurring population of cisco, or lake herring (*Coregonus artedi*).[4,5] Cisco require cold, deep, well oxygenated lakes, are considered to be excellent early responding indicators of changes in water quality, and contribute to exceptional forage opportunities for gamefish. Although cisco are no longer present in the Lake, water quality has improved over the years, and the Lake may once again be able to support this fish in the future. Additionally, as is further described in Chapter Two, the Lake's watershed contains critical species habitat areas and a variety of wetlands, uplands, and woodlands. The watershed likely supports a large number of resident animal species, including several species of reptiles and amphibians, small and large mammals, insects, and invertebrates, as well as a number of transient bird species that may be found in the area during seasonal migrations.[6]

1.3 LAKE PROTECTION GOALS

General lake protection goals that aim to maintain and enhance the Lakes' assets were developed as a part of this planning process. The goals listed below were developed in consultation with the LWC, the City of Delafield, the Village of Nashotah, and the public. The goals also directly address objectives established in the Waukesha County Comprehensive Development Plan and the Waukesha County Land and Water Resources Management Plan,[7,8] and helps provide additional detail regarding the sources of phosphorus described in the 2006 USGS report.[9]

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[3] *Wisconsin Department of Natural Resources Bureau of Fisheries and Habitat Management,* Wisconsin Lakes*, WDNR Publication FH-800, 2009.*

[4] *A.R. Cahn, "An Ecological Study of Southern Wisconsin Fishes, The Brook Silversides (*Labidesthes sicculus*) and the Cisco (*Leucichthys artedi*) in Their Relations to the Region,"* Illinois Biological Monographs *Volume XI, Number 1, University of Illinois, 1927.*

[5] *Recent fishery surveys suggest that Nagawicka Lake's cisco population is severely depleted or extirpated. For more information, please consult the following reference: J. Lyons, J. Kamp, T. Parks, and G. Sass,* The Whitefishes of Wisconsin's Inland Lakes: The 2011-2014 Wisconsin Department of Natural Resources Cisco and Lake Whitefish Survey*, Fisheries and Aquatic Research Section, Wisconsin Department of Natural Resources, February 2015.*

[6] *These estimates are based on bird, amphibian, and reptile databases for the Region.*

[7] *Waukesha County Department of Parks and Land Use,* A Comprehensive Development Plan for Waukesha County, Waukesha, Wisconsin*, February 24, 2009, www.waukeshacounty.gov/ctydevplan.*

[8] *Waukesha County Department of Parks and Land Use,* Waukesha County Land and Water Resource Management Plan*, 2012.*

[9] *H. S. Garn, D. M. Robertson, W. J. Rose, G. L. Goddard, and J. A. Horwatich.,* Water Quality, Hydrology, and Response to Changes in Phosphorus Loading of Nagawicka Lake, a Calcareous Lake in Waukesha County, Wisconsin*, U. S. Geological Survey, Scientific Investigations Report 2005-5273, 2006, pubs.usgs.gov/sir/2006/5273.*

- Examine the Lake's aquatic plant community
  - Document the status of the Lake's aquatic plant community, with particular emphasis on the occurrence and distribution of nonnative species. Use this information to better understand the changes and dynamics of the Lake's aquatic plant community.
  - Evaluate the impact of aquatic plants on Lake use and habitat value.
  - Identify measures and methods useful to reduce the extent and abundance of nonnative aquatic plant species.
  - Reduce the risk of allowing nonnative aquatic species to spread to other waterbodies, including downstream lakes, as noted in relevant previous Lake protection management plans.[10]
  - Provide the bulk of the information needed to successfully apply for an aquatic plant management permit.
- Update watershed condition descriptions, with particular emphasis on the Bark River watershed immediately upstream of the Lake. This includes identifying and quantifying potential point and nonpoint sources of pollution, nutrient and sediment inputs, and nutrient and contaminant balances. Also, provide conceptual examples of projects that could be undertaken to mitigate the impact of identified sediment and pollution sources.
- Identify the extent of existing and potential future water quality problems likely to be experienced in the Lake. This includes examining the Lake's water quality using physicochemical monitoring data collected as part of ongoing water quality monitoring programs. In addition, estimate future water quality changes and provide advice regarding appropriate future monitoring activity.
- Assess the degree and intensity of recreational water use in and around Nagawicka Lake.
- Formulate appropriate management objectives, action plans, public information and education strategies, ordinances, and other possible responses to the identified problems.
- Provide advice and concepts describing management, enhancement, and restoration measures that address identified issues of concern and could improve current and future Lake health and ecological resilience/resistance. This likely will include active measures as well as outreach and education.

Conscientiously implementing the actions recommended herein should provide an important step toward achieving the LWC's desired lake use/protection objectives over time.

[10] *SEWRPC Community Assistance Planning Report No. 262,* A Lake Management Plan for Nagawicka Lake*, 2001; and SEWRPC Memorandum Report No. 161,* An Aquatic Plant Management Plan for Nagawicka Lake, Waukesha County, Wisconsin*, 2006.*

INVENTORY FINDINGS AND RELEVANCE TO RESOURCE MANAGEMENT 2

Credit: SEWRPC Staff

Despite being a valuable resource to the community as briefly described in Chapter 1, human activity around the Lake and within its watershed subjects Nagawicka Lake to conditions that contribute to existing management challenges and could lead to future problems and concerns. To better define and understand these issues, and to help maintain water body characteristics supporting quality recreational use and the Lake's great latent ecological value, the Lake Welfare Committee (LWC) and the Southeastern Wisconsin Regional Planning Commission (Commission) executed an agreement to study the causes of community concern and to develop a management plan addressing these concerns.

Table 2.1
Issues of Concern

	Issues and Concerns
1	Water Quantity
2	Water Quality
3	Pollutant and Sediment Sources and Loads
4	Aquatic Plants
5	Cyanobacteria and Floating Algae
6	Shoreline Condition and Habitat Value
7	Recreational Use and Facilities
8	Fish and Wildlife
9	Plan Implementation

Source: SEWRPC

As a part of the planning process, issues of most concern were identified through various means, including an initial informational workshop with members of the Lake community, the annual meetings of the LWC, and field investigations conducted by Commission staff (see Table 2.1). These issues are the basis for the topics addressed in this management plan. This chapter provides information and interpretations that will 1) help answer questions posed by the LWC and concerned community members and 2) inform the development of concepts that help safeguard long-term Lake health and human-based value.

2.1 PHYSIOGRAPHY AND CULTURAL GEOGRAPHY

The condition and overall health of waterbodies are directly related to the natural and human-induced characteristics and features within the area draining to the waterbody. This section describes many features including the shape and arrangement of landscape features, the composition and arrangement of soil and rock, stream channel and Lake basin shapes, how water moves through the area, and how humans influence the landscape.

Given the connections between the practices around a lake and lake water quality, it is important to characterize the area that drains to a lake—its watershed—to determine potential pollution sources and risks to the lake's water quality. Several items need to be examined in order to complete this characterization, including:

- **The location and extent of a lake's watershed**—Before characterizing a watershed, its extent must be quantified. The delineation process involves carefully examining land surface elevation data to delineate the area from which water draining from the land surface eventually reaches a waterbody. This analysis provides the basis for determining whether potential pollutant sources threaten a waterbody. For example, if a pollution source is near a waterbody but outside the watershed, contaminated surface runoff from that source would not reach the waterbody, and, therefore, may not be an issue of concern in terms of water quality.

- **The type and location of existing land use within the watershed**—The extent and location of land use practices within the watershed can help predict the type and amount of pollution reaching a waterbody. Land use conditions can be represented with models to estimate total pollutant loads entering a waterbody, evaluate the relative contribution of certain land uses or areas, and predict consequences of land use change. Once loads are estimated, management efforts can be efficiently focused on those areas generating the greatest loads. For example, if agriculture is predicted to be the primary source of phosphorus to a water body, initial pollution reduction efforts may be focused on this land use.

- **The type and location of past land use changes within the watershed**—Being aware of past land use changes can provide context for understanding what caused past waterbody health issues, particularly when considered with contemporaneous water quality monitoring data or well-documented historical issues. For example, if a long-term lake property owner remembers or recorded the years of heavy aquatic plant growth, large algal blooms, or low or high water levels, those conditions can be correlated with historical land use changes to examine if something changed to cause an issue (such as an increase in impermeable surfaces or installation of stormwater infrastructure). This information can help offer insight into how a waterbody may react to similar future changes and situations.

- **The nature and location of planned land use within the watershed**—In addition to past and current land use in a watershed, planned land use changes can help estimate future conditions. This information helps target areas that may need active or pre-emptive management in the future, as well as estimate the potential type and magnitude of future pollution issues.

- **The location of known pollution sources in the watershed (if applicable)**—Many human activities contribute pollutants to waterbodies. Many potential pollutant sources are stringently regulated. However, some may continue to be significant pollution sources. An example is private onsite wastewater treatment systems (POWTS), commonly known as septic systems. POWTS can be a significant source of phosphorus when not properly maintained and are usually a source of chloride. Consequently, it is important to investigate whether POWTS exist within a watershed.

Location and Topography

Nagawicka Lake receives runoff from a 28,656-acre watershed draining portions of north-central Waukesha County and south-central Washington County.[11] The watershed trends northeast to southwest, and includes portions of ten municipalities including the City of Delafield; Villages of Chenequa, Hartland, Merton, Nashotah, Richfield, and Sussex; and the Towns of Delafield, Lisbon, and Merton (see Map 2.1). The watershed's most upstream reaches are located north of Bark Lake in the Village of Richfield, an area over 15 miles to the northeast of the Lake. Even though the watershed drains areas that far away, it is quite narrow, with a maximum width of approximately 5 miles. The Lake itself covers 1,010 acres in the City of Delafield and the Village of Nashotah.

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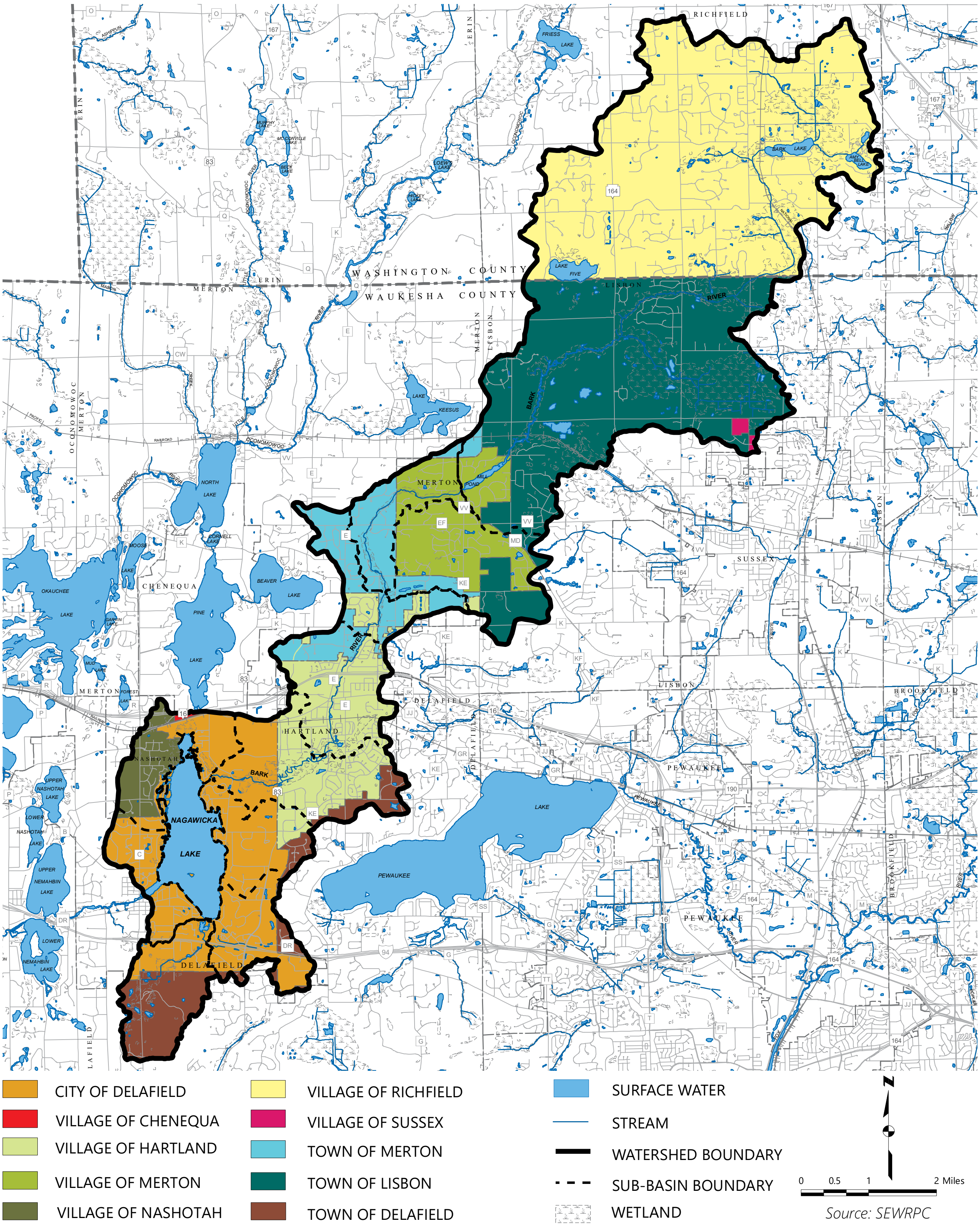
[11] *The Nagawicka Lake watershed boundary was delineated using two-foot interval ground elevation contours developed from a year 2003 digital terrain model.*

Map 2.1
Civil Divisions Within the Nagawicka Lake Watershed: 2019



The Lake and its watershed are within easy driving distance to downtown Milwaukee. As one of the largest and deepest lakes of the Waukesha County lake region, Nagawicka Lake is one the Milwaukee Metropolitan Area's premier water-based recreation lakes. These factors increase development and overall lake-use demand, which contributes to heavy pressure on the watershed's natural resource assets.

The ground surface elevation in the Nagawicka Lake watershed varies by approximately 235 feet, with elevations of approximately 889 to 890 feet above National Geodetic Vertical Datum, 1929 adjustment (NGVD 29) found along the Lake's shoreline to elevations ranging between 1050 and 1125 feet above NGVD 29 at the crest of prominent hills and ridges in southern and central portions of the watershed and across broad areas of the headwater area (see Map 2.2).

Areas of significant topographic relief are prone to long and/or steep slopes. Steeply sloping area are less likely to store or infiltrate water and are more likely to experience significant erosion, especially when actively cropped, developed, or urbanized. Eroded sediments are transported to lakes, streams, and wetlands where they settle and have the potential to cover desirable granular substrates. Furthermore, sediments often contain significant amounts of nutrients, and can contain a variety of pollutants. Slopes in the Nagawicka Lake watershed range from less than one percent to greater than 20 percent. As shown on Map 2.3, most areas within the Nagawicka Lake watershed are relatively level. Nevertheless, steeply sloping land is found throughout the watershed, including areas close to the Lake.

Geology and Soils

Essentially all of Waukesha County was covered by glacial ice until approximately 15,000 years ago. Eastern Waukesha County was overridden by glaciers flowing from the northeast out of the Lake Michigan Basin, depositing sediment known as the Oak Creek Formation and the New Berlin Member of the Holy Hill Formation. Glaciers overriding western Waukesha County followed Green Bay, Lake Winnebago, and other lowlands, and entered Waukesha County from the northwest depositing sediments known as the Horicon Member of the Holy Hill Formation The two lobes of glacial ice met and formed the prominent ridges of the Kettle Interlobate Moraine (commonly referred to as the "Kettle Moraine").

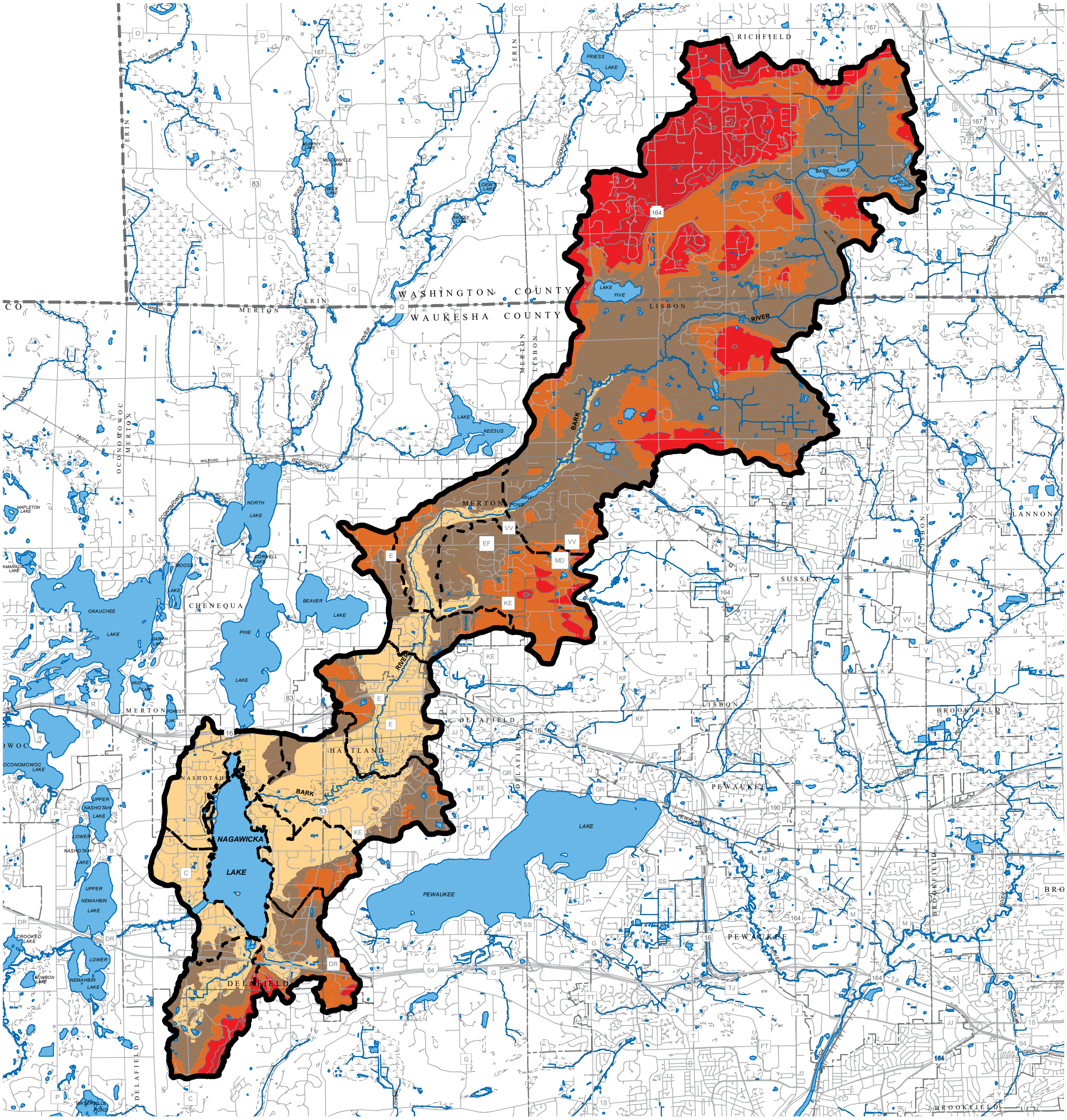
Glaciers entering Waukesha County transported vast quantities of unsorted sediment (diamicton) to the area and deposited these sediments under and at the distal end of glacial ice. When glacial diamicton is deposited directly by glacial ice, it is referred to as till. Till deposited under glacial ice is termed ground moraine, while that deposited near the wasting end of a glacier forms a terminal moraine. Melting glaciers release enormous volumes of water, and this water flows away from the glacier transporting and sorting sediment. Sorted glacial sediment is commonly referred to as glaciofluvial sediment (outwash) when deposited by flowing water or glaciolacustrine sediment (glacial lake deposits) when deposited in still water. The chaotic and rapidly changing environment near a melting glacial ice commonly creates complexly interlayered assemblages of till and water-lain sediment. Ice blocks can separate from the main body of ice and can be buried in these deposits. When the ice block melts, an irregular land surface marked by conspicuous steep-walled depressions ("kettles") results.

As is typical for most large lakes in northwestern Waukesha County, Nagawicka Lake is formed within the Kettle Interlobate Moraine, a region rich in permeable outwash. Nagawicka Lake is nearly completely surrounded by sandy and gravelly outwash, which also forms the bed and banks of the Bark River. Nagawicka Lake is a classic "kettle lake," formed when a large mass of ice separated from the glacier, was buried, and subsequently melted in place forming a steep-walled lake basin. The Lake's extreme southwest shoreline is different, being underlain by finer grained glacial till deposited near the contact between the Lake Michigan and Green Bay Lobes.[12] At least portions of the Lake's bed are directly underlain by glacial till.

The Bark River was situated at the edge of melting glacial ice and formerly carried tremendous quantities of water and sediment. Fine grained sediment was carried away, leaving large deposits of sand and gravel. The large and oftentimes steep walled valley in which the Bark River now flows is testimony to the volumes of water formerly carried by this stream, and the glacial meltwater's tremendous erosive power.

[12] *For more information on glacial geology, see: L. Clayton,* Pleistocene Geology of Waukesha County*, Wisconsin, Wisconsin Geological and Natural History Survey Bulletin 99, 2001.*

Map 2.2
Nagawicka Lake Watershed Topography and Physiography



ELEVATION IN FEET ABOVE NATIONAL GEODETIC VERTICAL DATUM, 1929 ADJUSTMENT

875 - 925
925 - 975
975 - 1,025
1,025 - 1,075
1,075 - 1,125
1,125 - 1,175
1,175 - 1,225

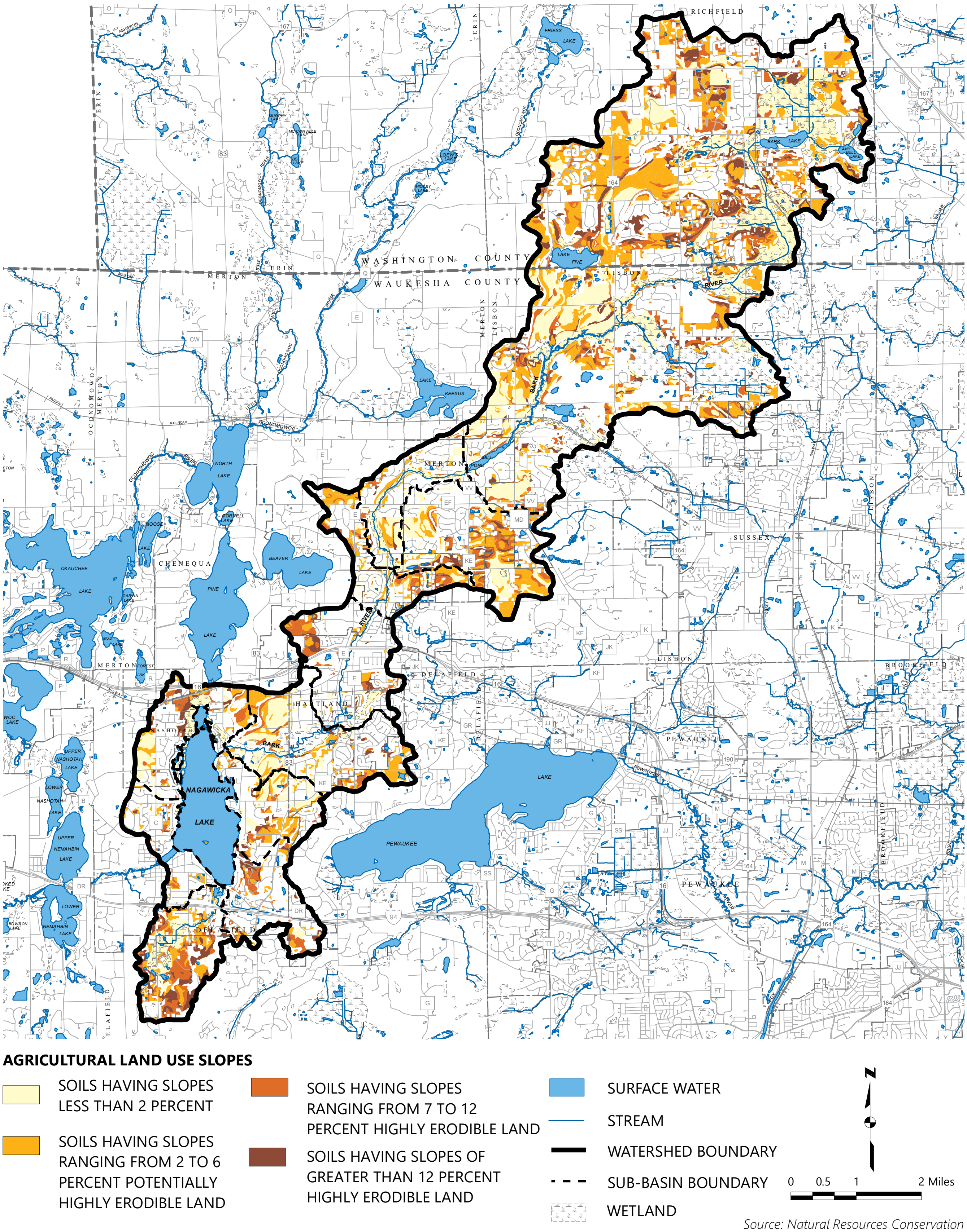
SURFACE WATER
STREAM
WATERSHED BOUNDARY
SUB-BASIN BOUNDARY
WETLAND

0 0.475 0.95 1.9 Miles

Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

Source: SEWRPC

Map 2.3
Slope of Areas Devoted to Agricultural Land Uses as of 2010 in the Nagawicka Lake Watershed



Source: Natural Resources Conservation Service and SEWRPC

The Bark River roughly parallels the course of a prominent bedrock valley. The central portion of the valley is underlain by dolomite of the Ordovician-age Sinnipee Group. Eastern portions of the watershed are at the margins of the valley and are underlain by narrow bands of erosion-prone shale of the Ordovician-age Maquoketa Formation. The bedrock uplands surrounding and punctuating the bedrock valley are capped with erosion-resistant Silurian-age Niagara Dolomite. Niagara Dolomite underlies portions of the River's headwater area, and small areas near Merton, Hartland, and south of Nagawicka Lake.[13] The Niagara Dolomite is visible in many areas in Waukesha County, including the quarries at Waukesha, Sussex, and Lannon. However, in most of the Lake's watershed, bedrock is buried by 50 to 400 feet of unconsolidated sediment (see Map 2.4). Bedrock is found at shallower depths in a small area southwest of the Lake, an area outside of the bedrock valley where Niagara Dolomite is found within 25 to 50 feet of the land surface.

Soils are the uppermost layers of terrestrial sediment and are the result of weathering and biological activity. The type of soil underlying the area depends on several factors, including landscape position and slope, parent material, hydrology, and the types of plants and animals present. Permeable, coarse textured soils of the Fox-Casco and Rodman-Casco Associations dominate the lower watershed, while soils of the Hocheim-Theresa association dominate the Bark River's headwater area in the Village of Richfield and Town of Lisbon (see Map 2.5). Fox-Casco and Rodman-Casco soils are both formed in outwash deposits, with Rodman-Casco soils generally having less topsoil, and being coarser grained and more droughty. Hocheim-Theresa soils are generally well drained and have a subsoil consisting of clay loam and silty clay loam, with parent materials being glacial till and loess (wind-deposited silt). Unlike many Southeastern Wisconsin watersheds, the Bark River watershed has comparatively little poorly drained soil. Nearly all of the poorly drained soil found in the watershed is found in depressions occupied by extinct lakes. Soils of the Houghton-Palms-Adrian Association are found in these areas.[14]

Hydric soils are formed when soils are saturated for extended periods of time. Hydric soils are often an indicator of saturated conditions near the land surface, ponding, or extended flooding, and are commonly associated with wetlands areas. About 12 percent of the Nagawicka Lake watershed is underlain by soils exhibiting some hydric characteristics. Most hydric soils are found in the eastern half of the headwater area of the Bark River, where expansive wetlands are found. The stretch of River between the Village of Hartland and the Lake, the areas surrounding the north end of the Lake, and a modest-sized area in the extreme southwestern corner of the watershed contain the bulk of the hydric soil area found downstream of the Merton Millpond (see Map 2.6). Many hydric soil areas were likely drained for human use or flooded to create open water areas during the past 180 years. Hydric soil areas are often sites of physical and biological processes that protect and sustain a lake's water quality and ecology, and therefore warrant protection.

Vegetation

Under pre-settlement conditions, the vegetation of the Nagawicka Lake watershed was dominated by forest in the northern headwater area. Aside from wetlands areas dominated by forbs and shrubs, the portion of the watershed in Washington County and extreme northern Waukesha County was forested by a mix of upland hardwoods including species such as sugar maple, basswood, various oaks, and, in the extreme northern periphery of the watershed, beech. The balance of the watershed was covered by scattered oaks and oak groves (see Map 2.7). The Nagawicka Lake watershed is somewhat unique in that it spans the transition area between woodlands that extended to the Atlantic Ocean and prairies that extended to the Rocky Mountains.

Much of the land in the watershed is well suited for agriculture (see Map 2.8). As such, much of the original vegetation was cleared to make room for farming and to provide raw materials to support initial settlement. Today's vegetation has been manipulated to support human wants and needs. Although much land is devoted to providing space for agriculture and residences, many areas still have vegetation supporting wildlife and other natural resource functions. Upland cover types are shown on Map 2.9. Wetlands, environmental corridors, floodplains, and other undeveloped areas also can host vegetation supporting wildlife and natural resource functions. These areas are discussed in subsequent sections of this chapter.

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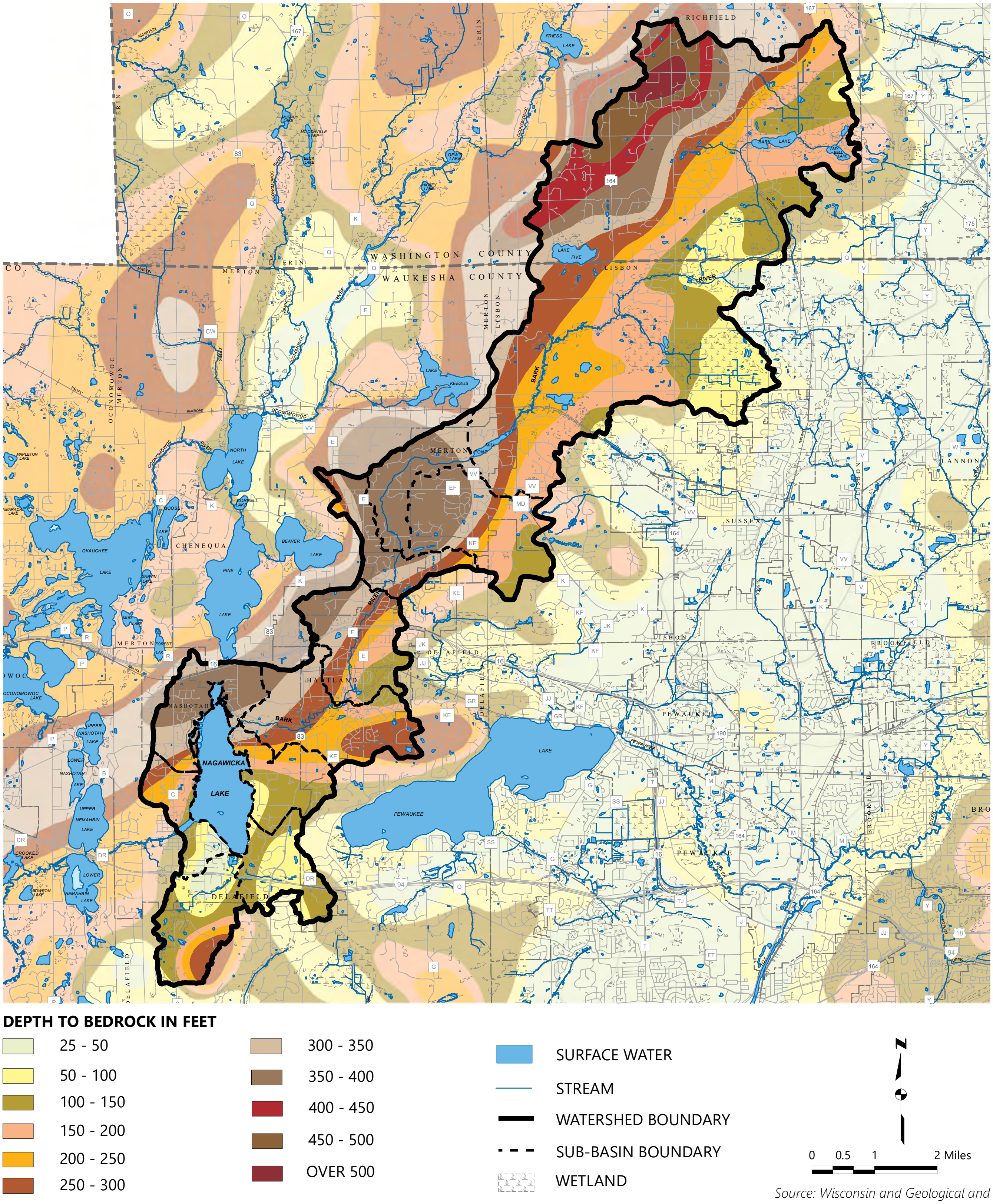
[13] *K.M. Massie-Ferch and R. M. Peters,* Preliminary Bedrock Geology of Waukesha County Wisconsin, Wisconsin*, Geological and Natural History Survey Open-File Report 2004-15B, 2004.*

[14] *J.A. Steingraeber and Charles A. Reynolds,* Soil Survey of Waukesha County, Wisconsin*, United States Department of Agriculture, 1971.*

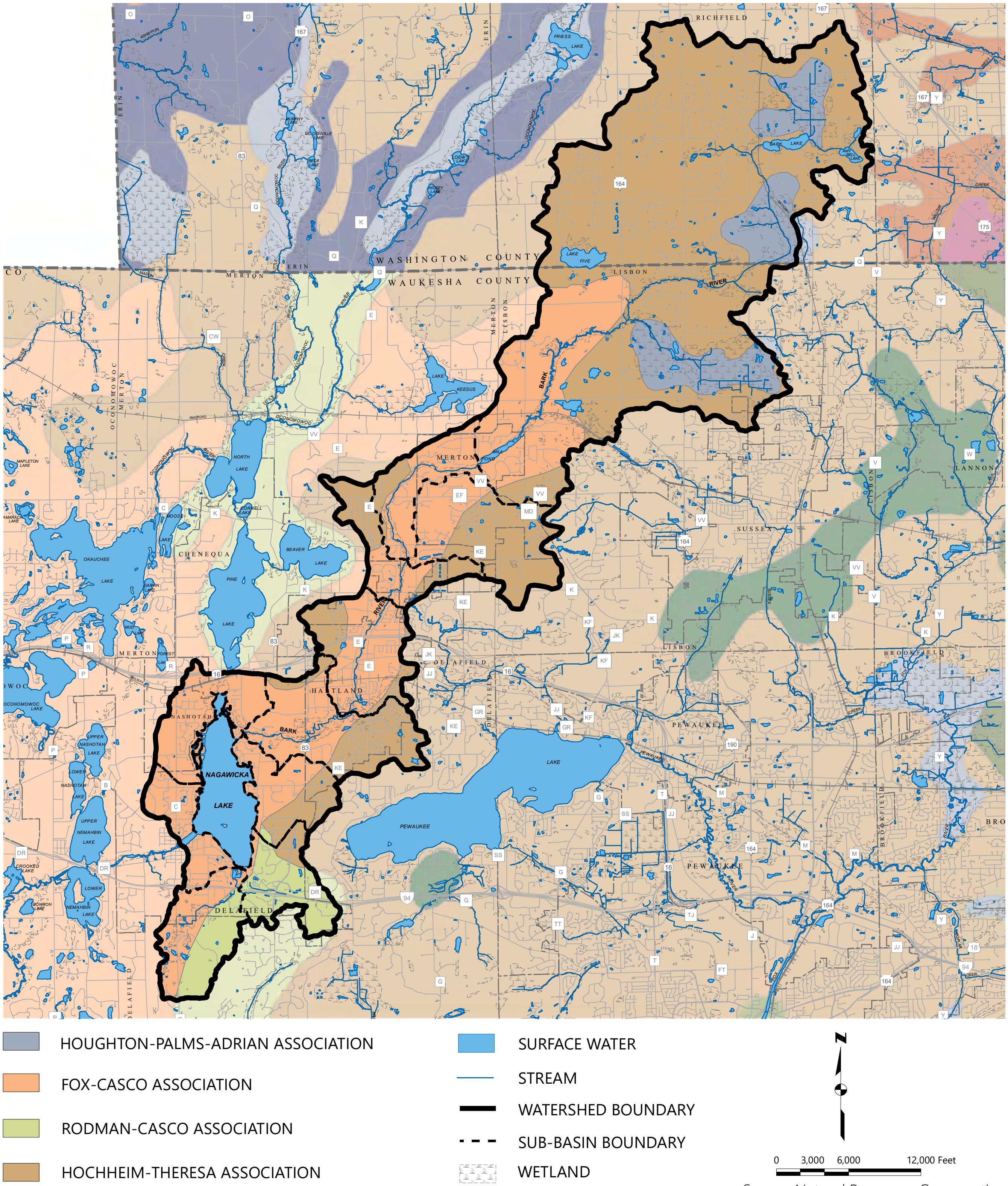
Map 2.4
Unconsolidated Sediment Thickness Underlying the Nagawicka Lake Watershed



Source: Wisconsin and Geological and Natural History Survey and SEWRPC

Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category. The information shown on this map is general in nature, and may not reflect localized variations.

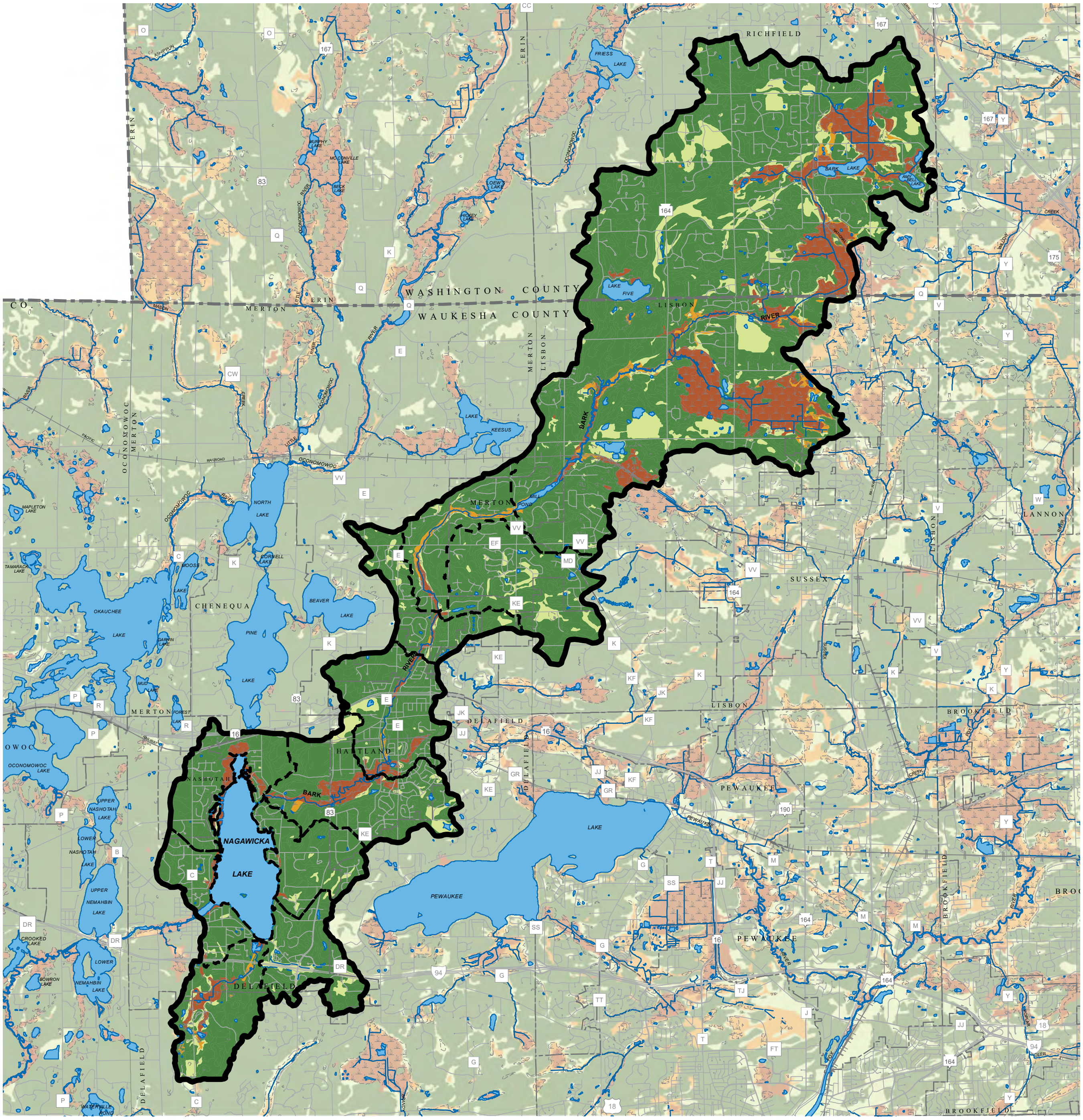
Map 2.5
Soil Associations Within the Nagawicka Lake Watershed



Source: Natural Resources Conservation Service and SEWRPC.

Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

Map 2.6
Extent of Hydric Soils Within the Nagawicka Lake Watershed



HYDRIC SOIL GROUPS

- HYDRIC
- PREDOMINANTLY HYDRIC
- PREDOMINANTLY NON HYDRIC
- NON HYDRIC

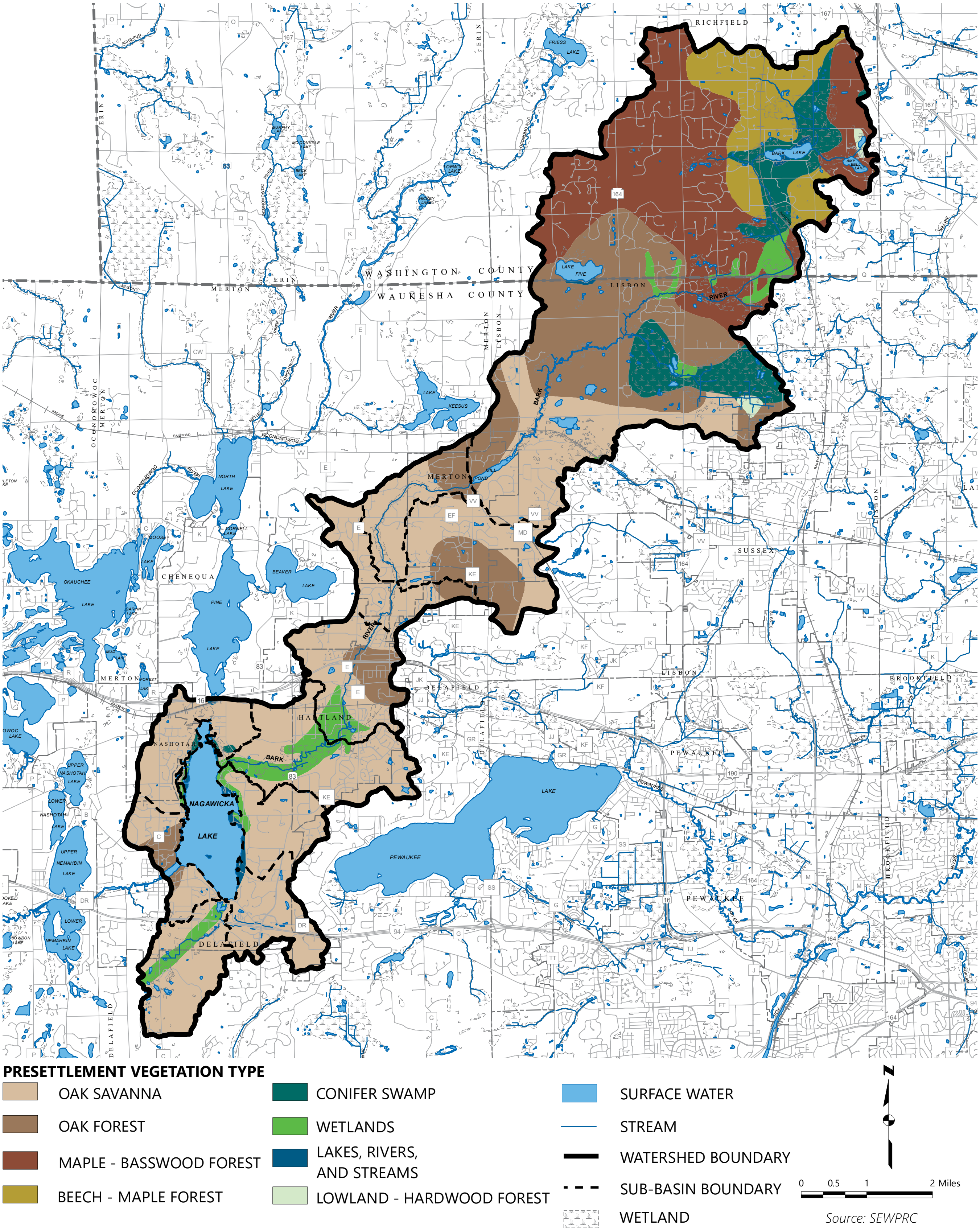
- SURFACE WATER
- STREAM
- WATERSHED BOUNDARY
- SUB-BASIN BOUNDARY
- WETLAND

0 0.5 1 2 Miles

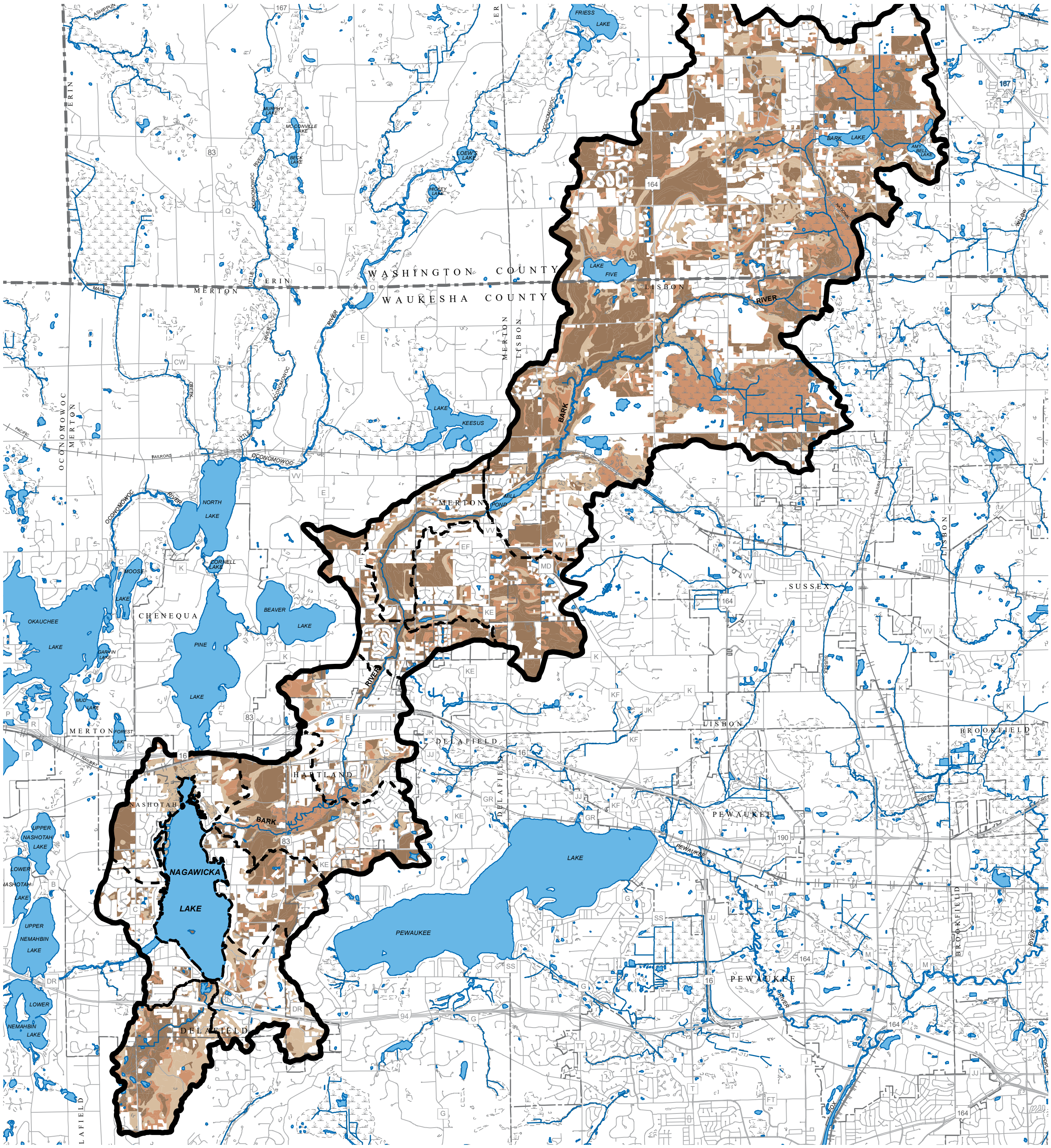
Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

Source: Natural Resources Conservation Service and SEWPRC

Map 2.7
Presettlement Vegetation of the Nagawicka Lake Watershed



Map 2.8
Federal and State Soil Classifications for Areas Devoted to Agricultural and Open Lands Uses as of 2010 Within the Nagawicka Lake Watershed



SOIL CLASSIFICATIONS

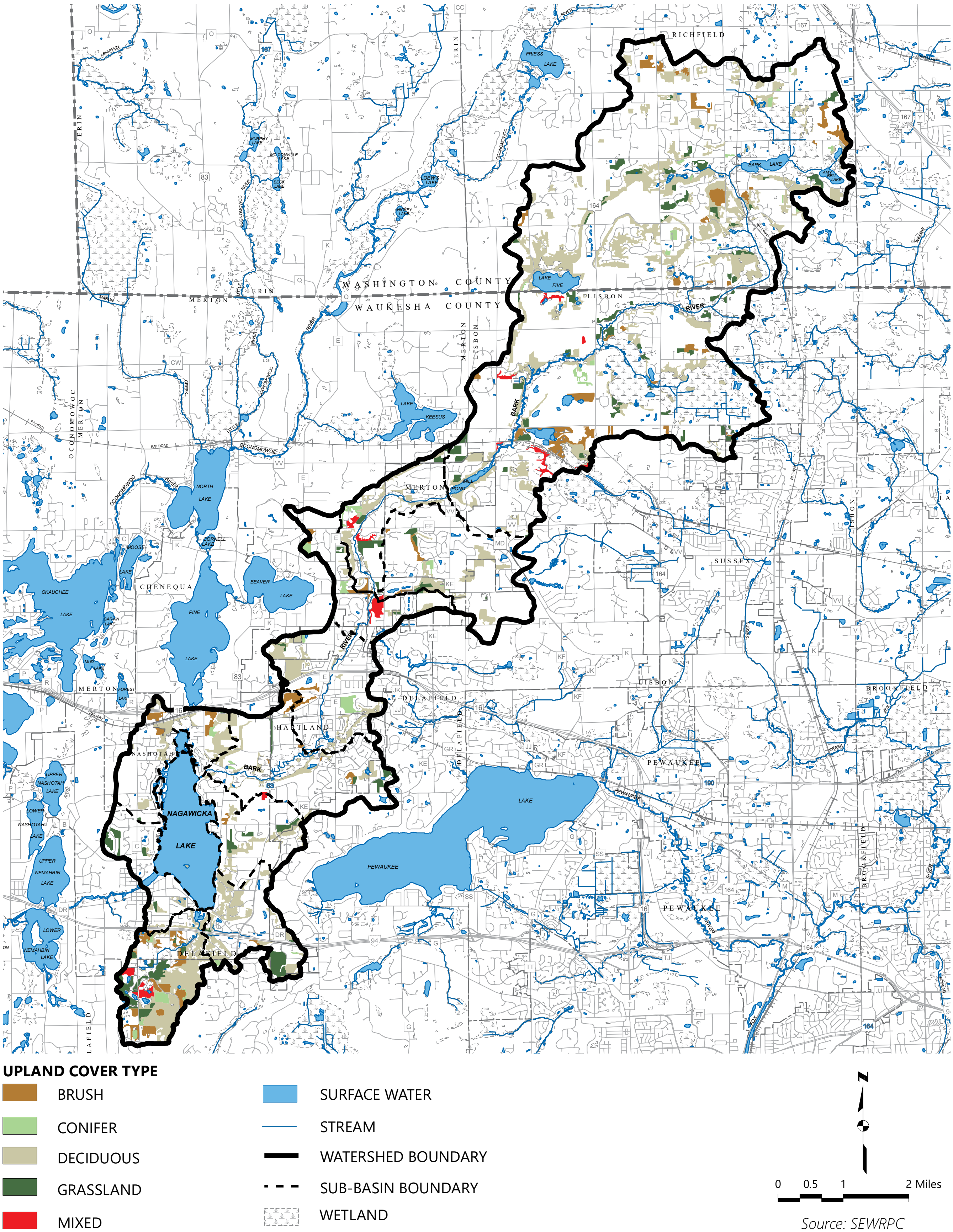
- NRCS PRIME AGRICULTURAL SOILS GROUP (INCLUDES PRIME IF DRAINED OR PROTECTED FROM FLOODING)
- SOILS OF STATEWIDE IMPORTANCE (NOT IN NRCS PRIME GROUP)
- OTHER AGRICULTURAL LANDS (NOT MEETING STATE OR FEDERAL CATEGORIES)
- SURFACE WATER
- STREAM
- WATERSHED BOUNDARY
- SUB-BASIN BOUNDARY
- WETLAND

N

0 0.5 1 2 Miles

Source: Natural Resources Conservation Service and SEWRPC

Map 2.9
Upland Cover Types Within the Nagawicka Lake Watershed: 2005



Source: SEWRPC

Water Resources

Nagawicka Lake has one named tributary—the Bark River. The Bark River is a third-order stream, receiving flow from many small tributaries, wetlands, groundwater, and one modest-sized lake (Bark Lake in Washington County).[15] The outlet of Nagawicka Lake is also the Bark River. Therefore, Nagawicka Lake is essentially a wide and deep portion of the Bark River. For the purpose of this report, the section of the Bark River upstream of Nagawicka Lake will be addressed as the "Upper Bark River" while the section downstream of the Lake will be called the "Lower Bark River". Furthermore, the overall watershed was subdivided into 11 sub-basins to facilitate examination and contrast differences (see Map 2.10). This section provides information regarding the hydrology, morphometry, general characteristics, and water resource management issues related to the Nagawicka Lake watershed.

Nagawicka Lake

The most conspicuous and well-known feature in the Nagawicka Lake watershed is the Lake itself. Nagawicka Lake receives runoff from 28,656 acres, over 80 percent of which is tributary to the upper Bark River. The Lake is the ultimate discharge point for portions of ten municipalities, all of which are gradually transitioning from rural to more urbanized land use, resulting in substantial changes to hydrology.

<u>Lake Origins</u>

The basin in which Nagawicka Lake lies was formed when a large block of ice broke away from the continental glacier, was buried by sediment, and subsequently melted (see "Geology and Soils" subsection for more information). The Lake is believed to have a similar genesis to other lakes found in the Kettle Moraine (e.g., Pine, Okauchee, and North Lakes).

The lakes of Waukesha County were frequented by Native Americans for thousands of years before European Settlement. In the Ojibwa language, "Nagawicka" translates to "there is sand" or "sandy", attesting to the sandy nature of the soils near the Lake. The first U.S. Public Land Survey was completed in the Nagawicka Lake area during 1836. This survey shows that the entire shoreline around the northern half of the Lake was fringed with broad wetlands (see Figure 2.1). A dam constructed across the Lake's outlet raised water levels in the Lake creating the Lake dimensions observed today.

<u>Morphometry and Hydrology</u>

The total area draining through Nagawicka Lake's outlet dam is 29,666 acres, including 1,010 acres occupied by Nagawicka Lake itself. Of the 28,656 acres draining to the Lake, 23,534 acres first drain to the Upper Bark River and its tributaries, and then to the Lake. Even though the Bark River is by far the largest tributary to the Lake, 5,122 acres drain directly to the Lake via small, unnamed tributaries, intermittent streams, or by overland flow.

Based upon sonar data collected during 1955,[16] Nagawicka Lake has a maximum reported water depth of 90 feet (see Map 2.11).[17] Despite its 90-foot maximum depth, most of Nagawicka Lake is much shallower. In fact, half of the Lake's total acreage is less than 10 feet deep (see Figure 2.2). The Wisconsin Conservation Department's bathymetric mapping was refined and a new map was published about 15 years ago.[18] Using

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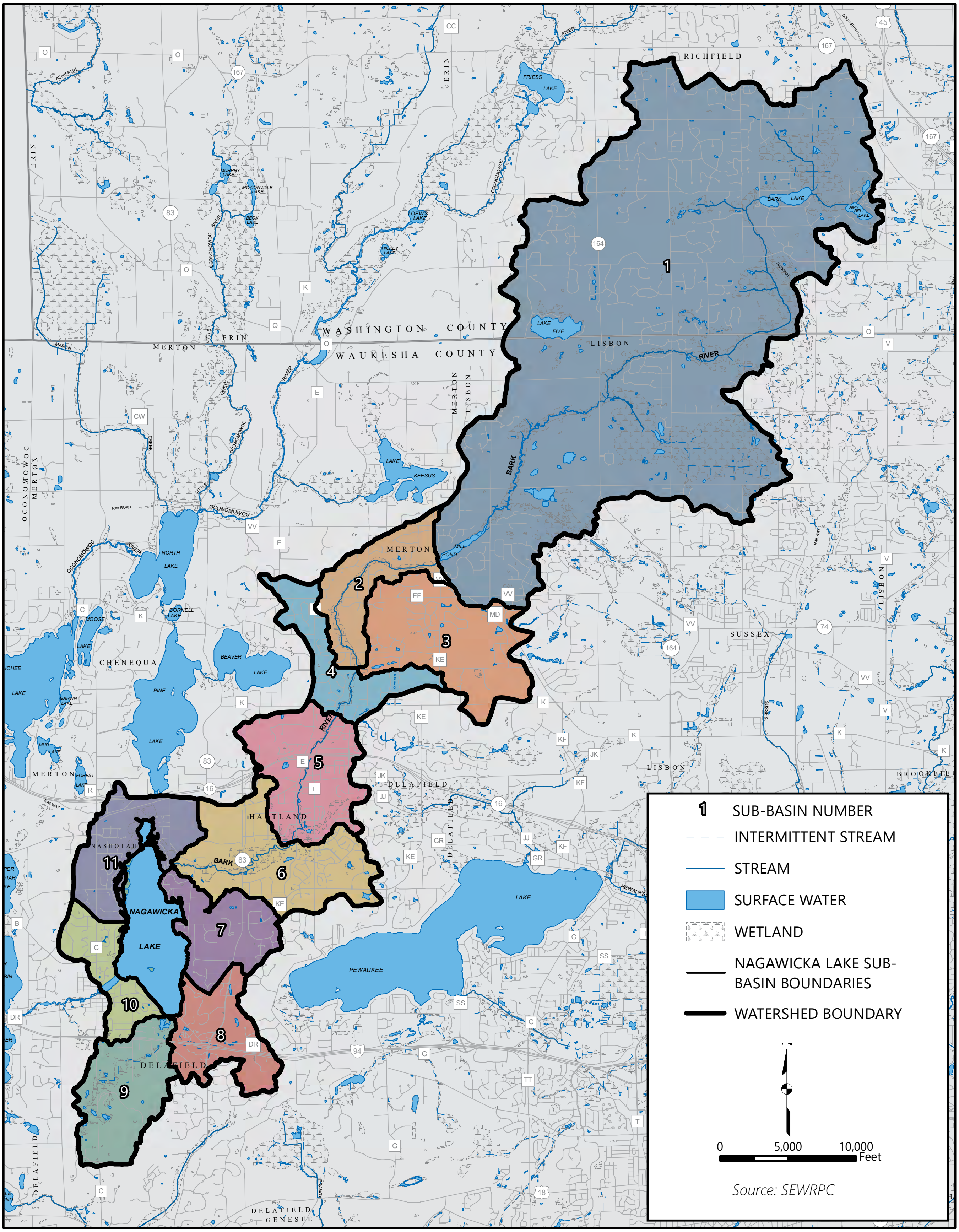
[15] *Stream order refers to a stream classification concept developed by Arthur Strahler and Robert Horton during the 1940s and 1950s. Headwater perennial tributaries are assigned a stream order of one and are labelled first order streams. When two first order streams converge, a second order stream is formed, when two third order streams converge, a third order stream is formed, and so on. When a lesser order stream converges with a higher order stream, the larger stream's order remains unchanged.*

[16] *Wisconsin Conservation Department,* Lake Survey Map: Nagawicka, Merton, Waukesha County*, May 12, 1955.*

[17] *As is common with lakes everywhere, the reported surface area and depth of the Lake varies. Surface area measurements are somewhat subjective, especially when lakes are fringed with marshland and low areas. Water elevations commonly fluctuate and can greatly influence the size of lakes. Shoreland vegetation may change over time, making it appear as if there have been changes in the shoreline. Lake bathymetric maps are commonly imprecise and old and may not fully reflect actual present-day water depths.*

[18] *Mapping Specialists, Limited,* Nagawicka Lake Enhanced Wall Map*, 2002/2006.*

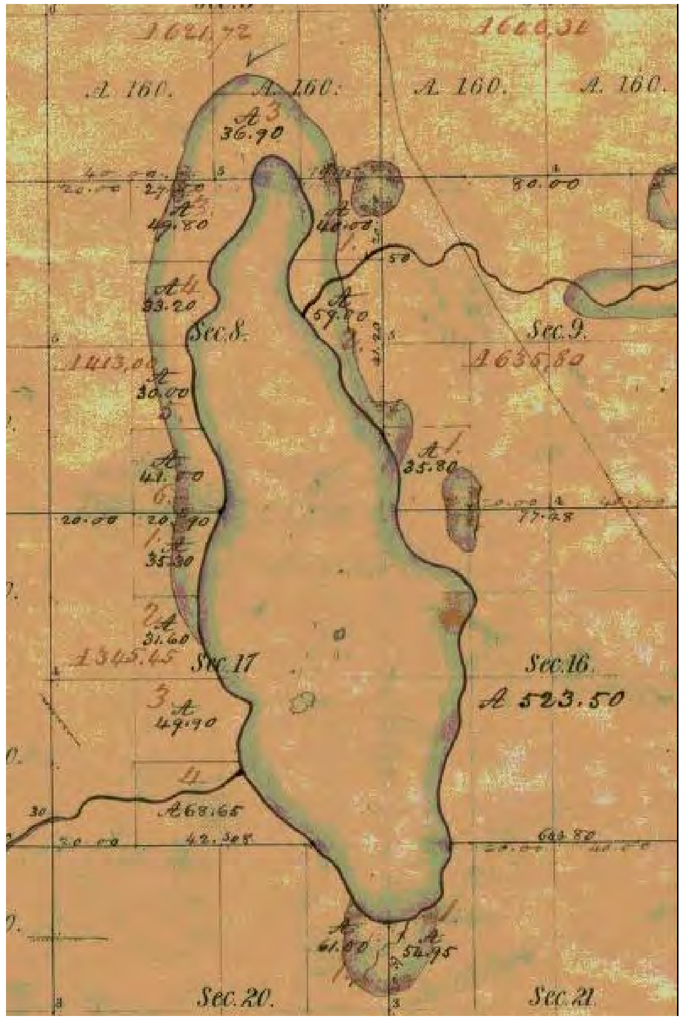
Map 2.10
Nagawicka Lake Watershed Sub-Basins Defined as Part of the Current Study



these refined contours, the Lake typically has a volume of about 26,000 acre-feet.[19] Roughly half of the Lake's total volume is found in waters greater than 20 feet deep (See Figure 2.3). Another revised bathymetric map is available online, but the source of the revised water measurements is unclear.[20] It should be noted that a dam artificially controls water elevation, increasing the Lake's water depth and surface elevation by about seven feet.[21] Operable gates and a millrace integral to the dam allow the water surface elevation and the volume of water stored in the Lake to be manipulated (see the following sections for more detailed information about Lake water levels and the outlet dam configuration).

The U. S. Geological Survey (USGS) completed a water budget for Nagawicka Lake during 2003 and 2004.[22] This study concludes that the Bark River contributes approximately three-quarters of Nagawicka Lake's water supply. The balance of Nagawicka Lake's water supply is derived from precipitation falling directly upon the Lake (12 percent), groundwater directly entering the Lake (7 percent), and the balance contributed by small tributaries and surface runoff that directly enters the Lake. The contribution of direct tributaries to the Lake varied between 6 and 9 percent, with higher percentages contributed during years with more abundant precipitation. It should be remembered that groundwater supplies a large percentage of the Bark River's and the tributary streams' flow. Therefore, groundwater is a dominant contributor to the Lake's overall water budget.

Figure 2.1
1836 Plat Map



Source: University of Wisconsin-Madison Library

The USGS water balance study also reports that most water leaves the Lake through the outlet dam. During wet years, 90 percent of the water leaving the Lake exits through the outlet dam. During dry years, evaporation from the Lake's open water area increases, decreasing the outlet dam's outflow to 82 percent of the water entering the Lake. The USGS report suggests that only one percent of the water leaving the Lake infiltrates into the Lake's bed and shoreline in western portions of the Lake, contributing to groundwater systems to the west of the Lake.

Lake managers commonly use several morphologic/hydrologic based parameters to judge the potential for humans to influence lake conditions. Examples of such parameters are examined in the following text.

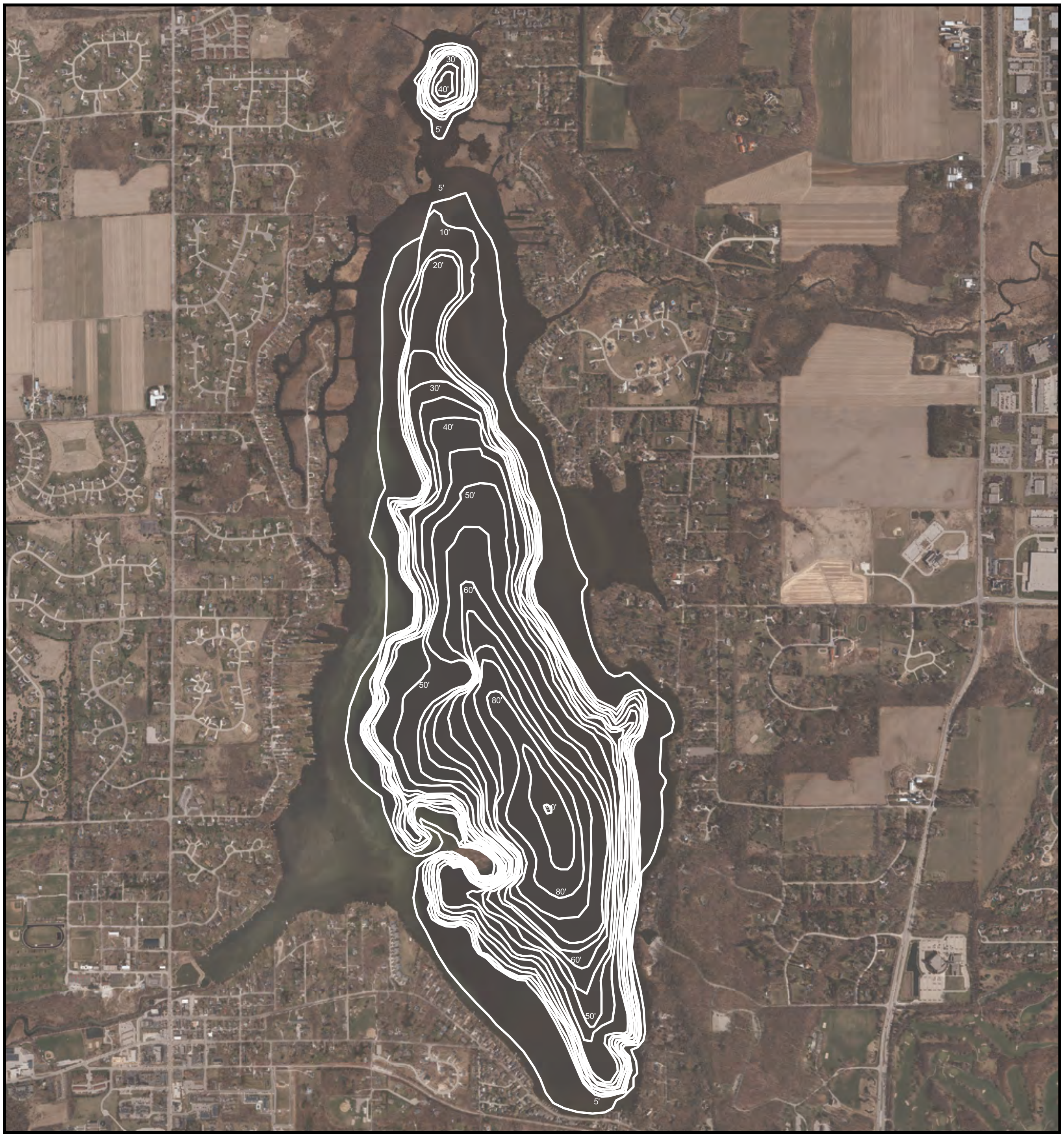
[19] *Lake bathymetry is often imprecisely mapped, and in many instances was collected decades ago with limited equipment. Variation in bathymetric maps changes computed lake water volumes. Additionally, a variety of methods exist to estimate lake water volume—the formula selected for determining lake volume can influence the results. This report computes lake volume by summing the horizontal volume of water lying between all available depth contours.*

[20] *This map may be viewed at webapp.navionics.com/?lang=en#boating@11&key=an%7DeG%60gozO.*

[21] *H. S. Garn, D. M. Robertson, W. J. Rose, G. L. Goddard, and J. A. Horwatich.,* Water Quality, Hydrology, and Response to Changes in Phosphorus Loading of Nagawicka Lake, a Calcareous Lake in Waukesha County, Wisconsin*, U. S. Geological Survey, Scientific Investigations Report 2005-5273, 2006, pubs.usgs.gov/sir/2006/5273/.*

[22] *Ibid.*

Map 2.11
Nagawicka Lake's Bathymetry: 1956 Replotted 2006



DATE OF PHOTOGRAPHY: APRIL 2015

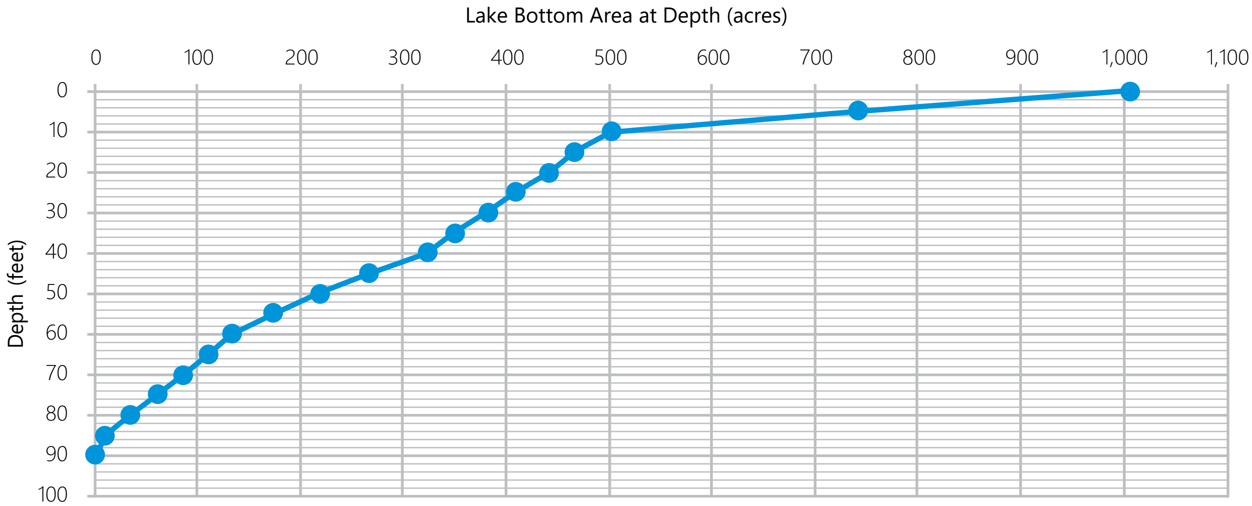
— 5' — 5 FOOT WATER DEPTH CONTOUR

N

0 500 1,000 2,000 Feet

Source: SEWRPC, Mapping Specialists (2006), Marine Construction LLC

Figure 2.2
Lake Depth Versus Surface Area, Nagawicka Lake



Note: This is a cumulative plot of the total surface area of the Lake with depths greater than or equal to depicted values. For example, roughly 500 acres of the Lake has water depths greater than 10 feet.

Source: Wisconsin Department of Natural Resources and SEWRPC

Watershed/Lake Area Ratio contrasts the size of a lake to its watershed. Lakes with higher ratios are typically considered more vulnerable to human influence and prone to water quality problems. However, the way the watershed is used can greatly influence the amount of pollutants carried to the Lake. As a rule of thumb, lakes with a watershed/lake area ratio greater than 10:1 often experience some water quality issues.[23] Nagawicka Lake's watershed/lake area Ratio is approximately 28:1 while typical Wisconsin inland lake have a watershed/lake area ratio of 7:1.[24] This finding suggests that the Lake is highly vulnerable to human influence and land use.

Retention Time refers to the average length of time needed to replace the lake's entire water volume.[25] In general, lakes with larger watershed/Lake area ratios have shorter retention times. Retention time is significant because it can help determine how quickly pollution problems can be resolved. For example, if retention times are short, pollutants are flushed out of a lake fairly quickly. In such cases, management efforts can likely focus on pollutant and nutrient loads contributed to the lake from the watershed. In contrast, lakes with long retention times tend to accumulate nutrients and pollutants. These can eventually become concentrated in bottom sediments. In this case, in addition to preventing external pollution, it also may be necessary to employ in-lake water quality management efforts.

Nagawicka Lake's average retention time of about 10 months is comparable to that for a typical Wisconsin inland lake, which has a retention time of about 11 months. Average retention time is based upon typical weather conditions. During long periods of atypically dry or wet weather, the amount of water evaporating from a lake and contributed by precipitation changes from the average condition, influencing retention time. The available data suggests that extended hot, dry weather periods could lengthen retention time to 20 months. Conversely, long periods of cool, wet weather could shorten retention time to about 9 months.

[23] *P.D. Uttormark and M. L. Hutchins,* Input Output Models as Decision Criteria for Lake Restoration, *University of Wisconsin Water Resources Center, 1978.*

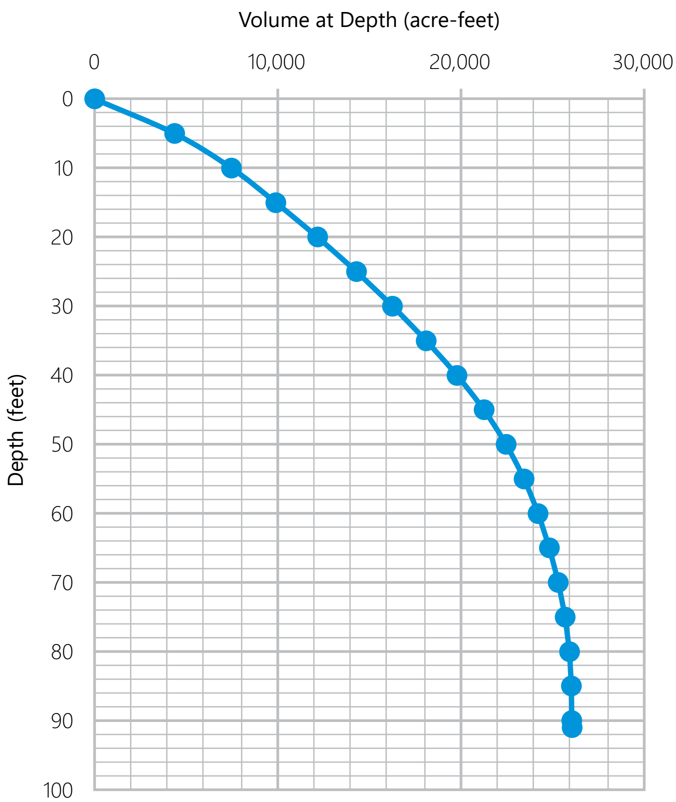
[24] *R.A. Lillie and J. W. Mason,* Limnological Characteristics of Wisconsin Lakes, *Wisconsin Department of Natural Resources Bulletin Number 138, 1983.*

[25] *The terms "flushing rate" and "hydraulic residence time" are also commonly used to describe the amount of time runoff takes to replace one lake volume. Flushing rate is the mathematic reciprocal of retention time, while hydraulic residence time is the same value as retention time. Therefore, while residence and retention time are expressed in years and have units of time, flushing rate is typically expressed as the number of times lake water is completely replaced by runoff in one year, and is therefore a rate (units/time).*

Shoreline Development Factor compares the length of a lake's shoreline to the perimeter of a perfect circle of identical area. Irregularly shaped lakes and lakes that include features as bays and peninsulas have higher shoreline development factors. Lakes with higher shoreline development factors are commonly more biologically productive and have larger proportions of shallow zones conducive to aquatic plant growth which may impede navigation. Such lakes are also more prone to greater numbers of lots per surface area of lake. Nagawicka Lake has a natural shoreline development factor of about 2.0, increasing to about 2.9 if artificial channels are considered.

Lake depth significantly effects lake water quality and biology. Deep lakes tend to stratify, a condition that inhibits mixing of the lake's entire water volume during summer and to a lesser degree during winter. Deep, well oxygenated lakes can host fish species that shallow lakes are incapable of supporting. However, stratification can foster anoxic water at depth and geochemical reactions that release nutrients to the water column and degrade water quality. Nagawicka Lake is one of the deepest lakes in Southeastern Wisconsin. The Lake regularly stratifies, making deep water areas vulnerable to anoxia.[26]

Figure 2.3
Lake Depth Versus Volume, Nagawicka Lake



Note: This is a cumulative plot of the total volume of the Lake contained in depths less than or equal to the depicted values. For example, roughly 12,000 acre-feet of the Lake's total volume is contained in the upper 20 feet of the Lake's water column.

Source: Wisconsin Department of Natural Resources and SEWRPC

Nagawicka Lake's high Watershed/Lake Area Ratio appears to be discordant with its average residence time value. This may possibly be explained by less water contributed per acre of watershed compared to typical Wisconsin Lakes. This is likely related to the relatively small area contributing groundwater to the Lake, portions of the Bark River which lose water to the Pewaukee Lake watershed, and human export of groundwater from the watershed. These factors are explained more fully in subsequent sections.

Water Surface Elevation

The volume of water entering and leaving the Lake varies depending upon changes in precipitation, evaporation, and the desire of humans. The original purpose of the Lake outlet dam was to store water for a commercial milling operation. The Lake outlet dam is no longer used for power production but continues to be used to artificially elevate and manipulate the water surface of Nagawicka Lake. The artificially raised water levels inundate much of the Lake's wetland fringe, make the northern kettle portion of the Lake more easily accessible to the main Lake basin, and expand the Lake's open water surface area.

Lake residents and users desire a predictable water elevation. In response to this desire, the Wisconsin Department of Natural Resources ruled that the Lake's water elevation should be maintained between 889.17 and 889.67 feet above NGVD 29. High runoff periods (e.g., caused by snowmelt and/or heavy rainfall) can cause Lake elevations to rise, while prolonged periods of dry weather can cause Lake levels to fall. Manipulating the outlet dam's gates helps increase or decrease the amount of water leaving the Lake and can therefore influence water levels and help keep the Lake's water surface elevation within the stipulated

[26] *Deep-water anoxia profoundly influences lake condition. The ramifications of this phenomenon are explored in Section 2.2, "Water Quality" and Section 2.6, "Fish and Wildlife.".*

range. At times, it can be desirable to anticipate oncoming weather conditions to help maintain Lake elevations within the desired range. For example, some dam operators hold water levels at the higher end of their operating range before times of the year when weather is commonly hot and dry in anticipation of falling lake levels and create additional storage capacity in late winter in anticipation of heavy spring runoff. Additionally, many Wisconsin lakes purposely lower water surface elevations during winter to help protect shoreline infrastructure and landscaping from ice damage.

The City of Delafield has monitored and recorded the Lake's water elevation since 2005 (see Figure 2.4). Extreme runoff events have caused the Lake's surface elevation to increase by over a foot, but such increases are transient and rapidly dissipate. Before 2010, water levels were drawn down about six inches during winter. Since 2010 water levels have been essentially static, varying very little except for short-term runoff events or brief drawdowns. This reflects changes made as part of a modified water level order issued by the Wisconsin Department of Natural Resources (WDNR) in October 2010. The new order did not change the Lake's stipulated water elevation range, but did relax the need to reduce water levels to the low end of the operating range between October 15 and March 15 of each year.[27] Since 2010, the Lake's water level has been consistently held at the maximum permissible level except for brief periods.

<u>Nagawicka Lake Outlet Dam</u>

Today's dam is not the original dam constructed to power a grist mill during initial European settlement. According to State records, the current dam was built in 1937 and has been repaired and retrofitted several times. The existing dam is fitted with two tainter gates and a center variable crest weir (see Figure 2.5). The gates occupy a total of about 35 feet in length and are rated to pass over 1,100 cubic feet per second. The dam's total crest length is 140 feet. The dam impounds approximately 7,000 acre-feet of water at normal Lake stage. Even though the dam is no longer used to produce power, the gates are actively used to try to stabilize the Lake's water surface elevation between 889.17 and 889.67 feet above NGVD 29.[28] For regulatory purposes, the dam is considered a large dam with a low hazard rating.[29] This rating requires the dam to pass a 10-year recurrence interval (10-percent-annual-probablity of occurrence) flood through its primary spillway, and a 100-year recurrence interval (1-percent-annual-probability of occurrence) flood through all spillways. The low hazard assignment also requires that the dam be inspected at 10-year intervals.

As opposed to a simple weir that passes more water as lake elevation increases, the Nagawicka Lake outlet dam primary spillway uses moveable gates that open from the bottom. Instead of most water passing over the top of the dam, the tainter gates draw water from up to several feet under the Lake's water surface. Large increases in outlet flow to compensate for heavy precipitation and runoff must be controlled by altering the dam's gate positions. Similarly, to maintain Lake level during extended periods of dry weather, the gates must be closed to a greater degree. As such, water discharge rates are affected by both gate position and water level in the Lake.

Streams

A complex network of streams contribute water to Nagawicka Lake. These streams range in size from the Bark River to ephemeral streams that only contain water during periods of heavy precipitation or snowmelt. This section examines the hydrology and morphology of streams contributing water to Nagawicka Lake and is subdivided into a section discussing the Bark River and its tributaries, and another discussing streams in the area that drains directly to Nagawicka Lake.

<u>Bark River and Its Tributaries</u>

Morphology and Hydrology

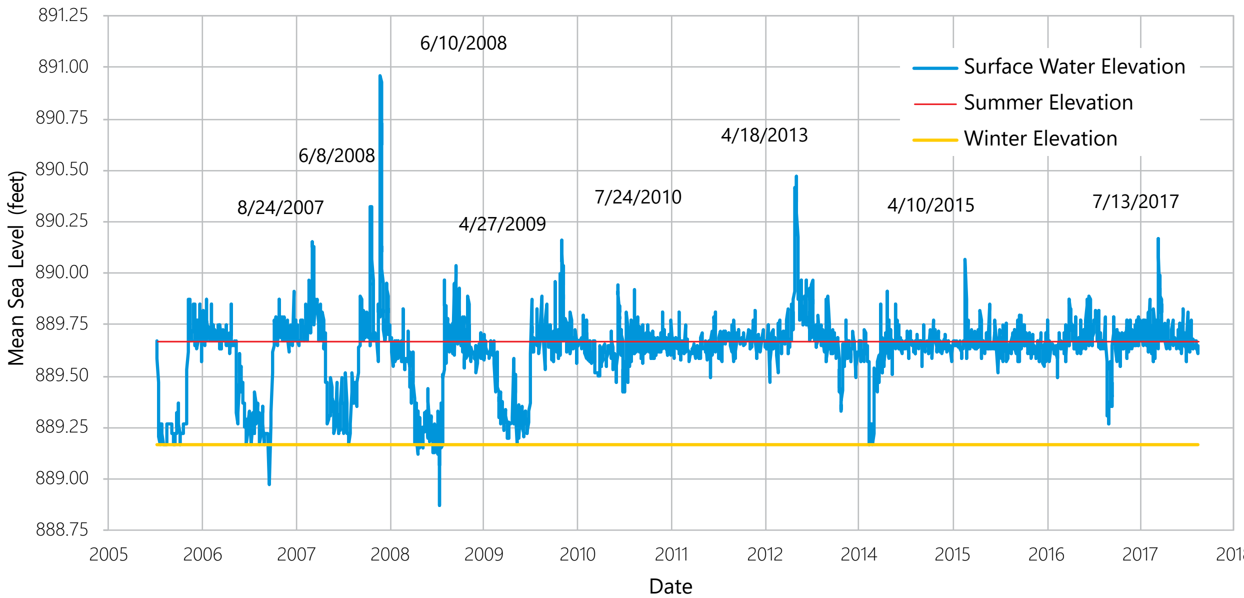
The Bark River watershed upstream of Nagawicka Lake (the Upper Bark River) covers 23,534 acres and comprises 82 percent of the area draining to Nagawicka Lake. The Bark River is a third order stream when it enters the Lake. The third order reach extends just upstream of the Village of Hartland. The Bark River's second order reach extends upstream beyond Bark Lake, essentially to its headwaters. The Bark River only

[27] *Wisconsin Department of Natural Resources,* Application of City of Delafield for a modification to the water level order setting levels or flows on Nagawicka Lake, City of Delafield, Waukesha County, IP-SE-2010-68-01851*, October 13, 2010.*

[28] *Wisconsin Department of Natural Resources,* Dam Report – Lake Nagawicka Dam*, 2018.*

[29] *Wisconsin Department of Natural Resources,* Dam Report – Merton Dam*, 2018.*

Figure 2.4
Nagawicka Lake Water Surface Elevation: 2005 – 2017



Source: City of Delafield

has one named tributary—Meadow Creek—which joins the Bark River a short distance downstream of Bark Lake. The portion of the Upper Bark River watershed downstream of the dam in the Village of Merton was studied in more detail under this plan. Therefore, to foster more detailed analysis, the area between the Merton dam and the Lake was subdivided into five sub-basins (see Map 2.10, Table 2.2).

The USGS operates a stream gaging station on the Bark River near Nagawicka Road. Data has been collected at this location since late 2002. The average daily flow at the gaging station is plotted versus time in Figure 2.6. Based upon the roughly 16 years of record, the typical average daily flow entering the Lake is 25.4 cubic feet per second. Flow varies considerably. Nevertheless, the River's flow at this location is between 10.5 and 62.6 cubic feet per second 90 percent of the time. Stream gaging data was also used to calculate the overall annual water yield from the upstream area, a value that incorporates all water sources contributing to the River's flow (i.e., surface runoff, groundwater, precipitation, and human contributions) less factors that reduce the River's flow (i.e., evaporation, water use by plants, human groundwater extraction/consumption/export, natural groundwater losses). This effort reveals that the Bark River watershed upstream of the Lake yields 6.8 inches per year during extremely dry periods, 11.1 inches per year during average weather conditions, and 14.6 inches per year during extended wet weather periods.

The WDNR's online Presto-Lite tool can be used to estimate typical stream flows (see Table 2.3). Even though it has limitations, the Presto-Lite tool provides a way to estimate the relative volume of water draining from the various sub-basins. Compared to USGS gaging station data, the Presto-Lite tool appears to underestimate peak and median overall watershed flows but overestimates overall watershed dry weather flow. This may be due to human influence in the watershed, specifically the presence of impermeable surfaces and older stormwater infrastructure not accounted for by the Presto-Lite tool. Impermeable surfaces are commonly related to higher-density land use, such as urbanized areas (see "Land Use" subsection for more information). The Village of Hartland is one of the most urbanized areas of the watershed. Pre-1990 stormwater infrastructure tends to rapidly remove runoff from the landscape and deliver it immediately without modulation to receiving water bodies. Stormwater infrastructure built before approximately 1990 is anticipated to yield more runoff volume over shorter periods of time and tends to yield little water during dry weather. The Village of Hartland has the largest areas in the watershed that are drained by storm sewer networks constructed before 1990. The stormwater inventory is discussed in more detail in the "Priority Sources/Lake and Stream Inventory" of Section 2.3, "Nearshore and Stream Channel Inventory" later in this chapter.

In addition to human manipulation of the landscape, other factors can influence runoff tools such as Presto-Lite. The Presto-Lite tool cannot account for many natural watershed-specific conditions. For example, groundwater conditions could affect estimated flow volumes. In the case of the Bark River, the portion of the Bark River within the Village of Hartland is believed to lose water through its bed to the groundwater flow system feeding Coco Creek and Pewaukee Lake. This would tend to cause Presto-Lite to predict higher dry weather flow than actually measured. The Presto-Lite estimates may be more accurate for the less developed portions of the Upper Bark River watershed (e.g., sub-basins 1, 3, and 6, see Figure 2.7 and Map 2.10). Since the entire watershed is rapidly urbanizing, Presto-Lite runoff estimates may be less accurate when considering future management implications.

Figure 2.5
Nagawicka Lake Outlet Dam

Source: SEWRPC

Typically, river channel gradients gradually decrease from headwater areas to a river's mouth. That is, headwater reaches are often the steepest stream reaches, with channel gradients progressively decreasing as one moves farther downstream. The Upper Bark River does not follow this paradigm. Instead, its headwaters are dominated by low gradient reaches that cross broad riparian wetlands and marshlands, while the steepest gradient reaches are located a modest distance upstream of its mouth. To illustrate this fact, the River falls less than five feet between its most distant mapped headwater area upstream of Bark Lake and the Washington/Waukesha County line, a channel distance of about 12 miles. The Bark River's main stem has a fairly consistent slope of less than 2.5 feet per mile (a slope of slightly less than 0.05 percent). The River's gradient remains gentle from the Washington-Waukesha county line to the Merton millpond, with a gradient of approximately 3.4 feet per mile, which is only slightly steeper than the headwater area. From the Village of Merton to Nagawicka Lake, the River drops 55 feet, an overall gradient of slightly more 15 feet per mile.

The portions of the Bark River downstream of Merton are punctuated with several high gradient reaches (see Figure 2.8). A particularly noteworthy stretch is the Nixon Park area in Hartland, where the River declines approximately 15 feet in less than a half mile, creating a gradient of slightly more than 35 feet per mile. This high gradient stretch was the location of the former Hartland Mill, and is likely a naturally occurring phenomenon. Below the Nixon Park area, the River crosses a low gradient stretch where it is again flanked by riparian wetland. This wetland area has some of the deepest water depths on the River below Merton, and likely has substantial habitat value.

Very little soft sediment is present in the Bark River below the Merton millpond. The stream is dominated by granular sediment, a feature consistent with its steep gradient. The appearance of a typical reach of the River below the Merton Millpond is illustrated in Figure 2.9.

Upper Bark River Dams

Dams were commonly built on perennial streams during the early phases of European settlement to provide power for sawmills, grain and feed milling, textile manufacturing, and various industrial enterprises (e.g., nail production, compressing air, shoe manufacturing, etc.). There is a dam on the Bark River upstream of Nagawicka Lake near Merton and there was formerly a dam on the River at Hartland. Each is described in the following text.

Merton Dam

The Merton Dam was first constructed in 1847. The dam powered a sawmill and later a grist mill.[30] According to WDNR records, the present dam was constructed in 1967. The dam creates about six feet of head and is over 700 feet long. The dam is fitted with a tainter gate and is rated to pass over 500 cubic feet per second. Pictures of the dam are included in Figure 2.10. The gates are used to manipulate water level in the millpond, which should be maintained between 947.92 and 948.22 feet above NGVD 29. For regulatory purposes, the dam is considered a large dam with a significant hazard rating.[31] This influences spillway conveyance sizing under Chapter 333, "Dam Design and Construction," of the *Wisconsin Administrative Code*. A significant hazard dam must pass a 50-year recurrence interval (2-percent-annual-probability) flood through its primary spillway, and a 500-year recurrence interval (0.2-percent-annual-probability) flood through all spillways. The significant hazard assignment also requires that the dam be more frequently inspected.

Hartland Dam

A grist mill was constructed during 1848 just upstream of East Capitol Drive, known at that time as Milwaukee Road (see Figure 2.11). The mill race extended from the reservoir to a mill just north of the railroad. A four and one-half story mill building was erected, and the area was commonly referred to as Hersheyville, after Christian Hershey, the mill

Table 2.2
Hydrology and Morphometry of Nagawicka Lake

Parameter	Nagawicka Lake
Size and Shape	
Open Water Surface Area[a]	1,010 acres
Contributing Watershed Area[b]	28,656 acres
Shoreline Length[c]	9.1 miles
General Lake Orientation	North-South
General Shape	Irregular Elongated Oval
Maximum Length	2.8 miles
Maximum Width	1.3 miles
Shoreline Development Factor[d,e]	2.04
Depth	
Maximum Depth	90 feet
Mean Depth	26 feet
Area Less Than 3 Feet Deep	161 acres (16%)
Area Greater Than 20 Feet Deep	442 acres (44%)
Hydrology	
Lake Volume	26,077 acre-feet
Lake Type	Drainage/Two Story
Residence Time:[f]	
Average Weather Years	0.8 years
Dry Weather Years	1.0 years
Wet Weather Years	0.5 years

[a] *The surface area of Nagawicka Lake has been variously reported as 981 acres by the Wisconsin Department of Natural Resources in 2007; 957 acres by Waukesha County and the Southeastern Regional Planning Commission in 2006 and 1999, 917 acres by SEWRPC in 2001, and 1,026 acres by SEWRPC in 1979. Lake area values reported in this report are based on the most recent measurements made from 2015 orthophotography using ArcGIS. Apparent lake areas can vary on account of a number of factors (e.g., water elevation, shoreline vegetation, tree cover, season).*

[b] *Does not include Nagawicka Lake area.*

[c] *Shoreline length value in the above table excludes shoreline length attributable to artificial channels and islands. Shoreline length increases to 16 miles if artificial channels and islands are included.*

[d] *Shoreline development factor is the ratio of the shoreline length to the circumference of a circle of the same area. It can be used as an indicator of biological activity (i.e., the higher the value, the more likely the lake will be to have a productive biological community). Higher shoreline development factors are also commonly associated with lakes with a higher number of homes per acre of lake surface.*

[e] *The shoreline development factor listed in the table excludes shoreline length associated with artificial channels and islands. If shoreline associated with these features is included, the shoreline development factor increases to 2.91.*

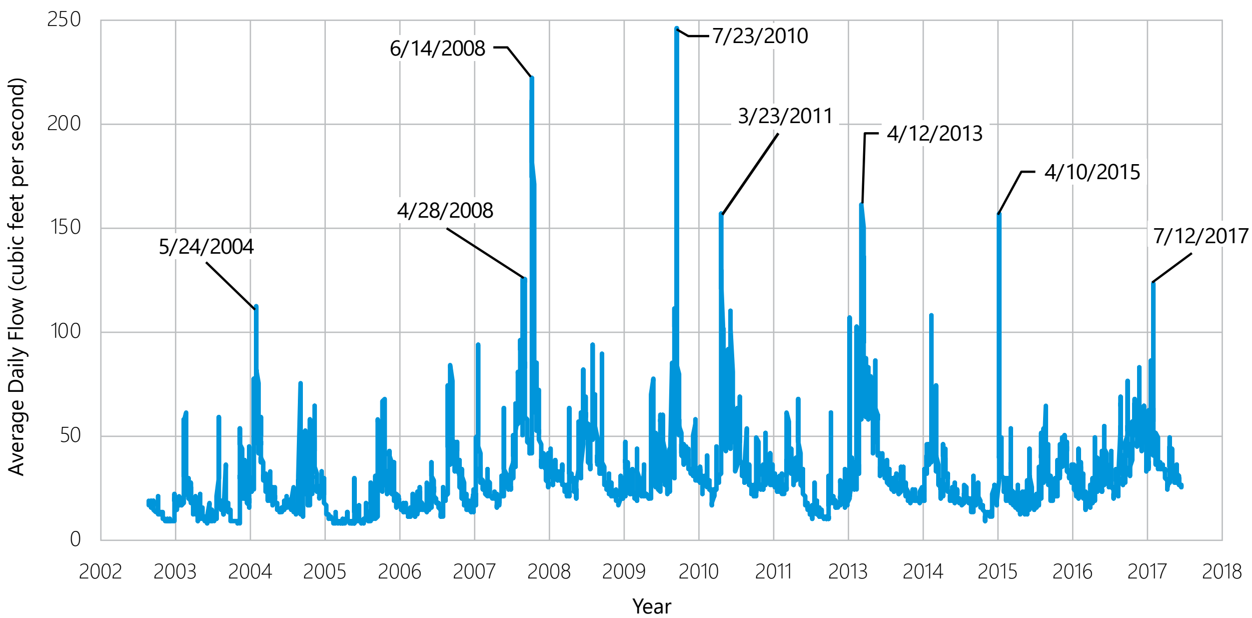
[f] *Residence time is the number of years required for natural water sources under typical weather conditions to fill the lake one time. Natural water sources include runoff from surrounding areas, precipitation falling directly upon a lake, water entering from tributary streams, and water contributed to a lake by groundwater.*

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, and SEWRPC

[30] *Western Historical Company,* The History of Waukesha County, Wisconsin*, 1880.*

[31] *Wisconsin Department of Natural Resources,* Dam Report – Merton Dam*, 2018.*

Figure 2.6
Bark River Average Daily Flow at Nagawicka Road: 2002 – 2017



Source: U.S. Geological Survey

owner.[32] The dam and mill buildings no longer exist, but the former mill and dam site can be recognized by the high gradient stream reach near Nixon Park.

Lake-Direct Drainage Watersheds

Although the Bark River is by far the largest tributary to Nagawicka Lake, 5,122 acres drain directly to the Lake. Only one mapped stream drains this area, entering the Lake from the southwest. The remainder of the lake-direct watershed drains through a diffuse network of ephemeral natural watercourses, storm drains, and general overland flow. To allow for more detailed examination, the Lake-direct drainage area was subdivided into five sub-basins (see Map 2.10). Characteristics of these sub-basins are summarized in Table 2.4.

Aside from sub-basin 9, which extends southwest of the Lake and into the undeveloped areas south of IH 94, the Lake-direct watersheds are highly urbanized, with most areas developed before 1990 (see "Historic Urban Growth" and "Land Use" subsections). Sub-basin 9 is by a wide margin the least developed portion of the watershed feeding Nagawicka Lake (see Figure 2.12). In contrast, sub-basin 10, which includes portions of downtown Delafield, is the most urbanized area contributing flow to Nagawicka Lake. Even though the Lake's shoreline area has been essentially fully developed for many decades, the sub-basin areas inland from the lakeshore continue to urbanize in all Lake-direct drainage sub-basins (see Figure 2.12). In general, the percentage of land in the Lake-direct drainage area more than doubled between 1963 and 2010. Some sub-basins have met or are approaching full build out.

The USGS evaluated the hydrology of the areas draining directly to Nagawicka Lake.[33] The USGS divided the Lake-direct drainage area into three sub-basins instead of five as was done for this study. The Commission's sub-basins 8 and 9 at the south end of the Lake closely correspond with USGS subwatersheds 1 and 2, respectively. The USGS measured flow from these subwatersheds as part of their study. The Commission's sub-basins 7, 10, and 11 cover essentially the same area as USGS subwatershed 3. Given the diffuse runoff from this area, the USGS could not measure flow from this area, and instead estimated flow using a model and they assumed the watershed conditions were similar to sub-basin 8.

[32] *Hartland Historical Society,* A brief history of the Village of Hartland*, Wisconsin, undated.*

[33] *Garn, 2006,* op. cit.

Table 2.3
Upper Bark River Tributary Flow Estimates

Sub-Basin Number	Average Daily Flows (cubic feet per second/percent of Upper Bark River watershed total flow)[a]		
	Very High Flow Periods[b]	Median Flow Periods[c]	Very Dry Periods[d]
1	33.00/71	13.30/64	7.52/62
2	1.70/3.6	1.20/5.8	0.75/6.2
3	2.86/6.1	1.15/5.6	0.69/5.7
4	2.74/5.9	1.55/7.5	0.88/7.2
5	2.90/6.2	1.50/7.3	1.06/8.7
6	3.50/7.5	2.00/9.7	1.30/10.7
Total 1-6[e]	46.70/100	20.70/100	12.2/100

[a] *Flow estimates computed using WDNR's online Presto-Lite tool. The estimates cannot account for all watershed-specific variables. Resultant values may overestimate or underestimate actual flow.*

[b] *Flows exceeding this value recur less than 5 percent of the time.*

[c] *Flows exceeding this value recur 50 percent of the time.*

[d] *Flows less than this value recur 5 percent of the time.*

[e] *Rounding in individual sub-basin values creates small discrepancies.*

Source: Wisconsin Department of Natural Resources Presto-Lite tool

USGS data demonstrates that the highly urbanized nature of sub-basins 7, 8, 10, and 11 leads to a situation where most of the water volume draining from these areas occurs during short, intense, runoff events. These flows rapidly subside, and the drainageways remain dry during most of the year. Short, intense runoff events are commonly related to impermeable surfaces and older engineered stormwater conveyance infrastructure, and such events increase streams' abilities to erode their beds and banks and deliver sediment and pollutants to receiving waterbodies. Post-1990 development generally includes features to detain water, allowing for peak flows to be reduced. Many stormwater detention features are present in the more recently developed portions of sub-basins 8 and 10 (see "Pollution Mitigation Strategies" in Section 2.3, "Nearshore and Stream Channel Inventory" later in this chapter for more details).

The USGS study estimated the amount of water entering the Lake from the Bark River and Lake-direct tributary areas. Based upon the results of the two-year study, approximately 90 percent of the surface water runoff draining into Nagawicka Lake entered via the Bark River. The remaining 10 percent drained from the Lake-direct drainage area. Sub-basin 8, which includes the commercial area at the intersection of IH 94 and STH 83 contributed about 1.1 percent of the surface-water runoff entering the Lake. Sub-basin 9, which drains the relatively undeveloped southwest corner of the Lake's watershed, contributed 3.2 percent. The remaining Lake-direct drainage area (sub-basins 7, 10, and 11) contributed 4.9 percent of the surface water entering Nagawicka Lake. Applying these percentages to the 13 years of runoff data available for the Bark River allows the range of flows contributed by the sub-basins to be estimated (see Table 2.5).

The volume of water contributed by each sub-basin can be used to compare a watershed's total water yield per acre. Water yield includes net surface runoff, groundwater discharge to water bodies, and artificial contributions less water lost from the stream to groundwater, evaporation, plants, and human water supply needs. Even though urban streams are often very flashy, with high flows during runoff events, and low flows during fair and dry weather, urbanized areas typically yield more water. This counterintuitive situation is largely related to decreased infiltration, and associated with this, decreased water uptake by plants and reduced groundwater recharge. Table 2.6 sets forth the Upper Bark River's overall watershed yield from the Lake-direct drainage sub-basins.

The highly urbanized Lake-direct sub-basins surprisingly yield less water per acre than the moderately urbanized Upper Bark River watershed. Sub-basin 9, which represents the least urbanized portion of the entire Nagawicka Lake watershed, still contributes less water per acre than the Upper Bark River Watershed. The low water yield of the Lake-direct sub-basins may be related to a variety of factors. For example, large portions of the Lake-direct drainage sub-basins do not contribute water to the groundwater flow system feeding the Lake, reducing overall water yield.

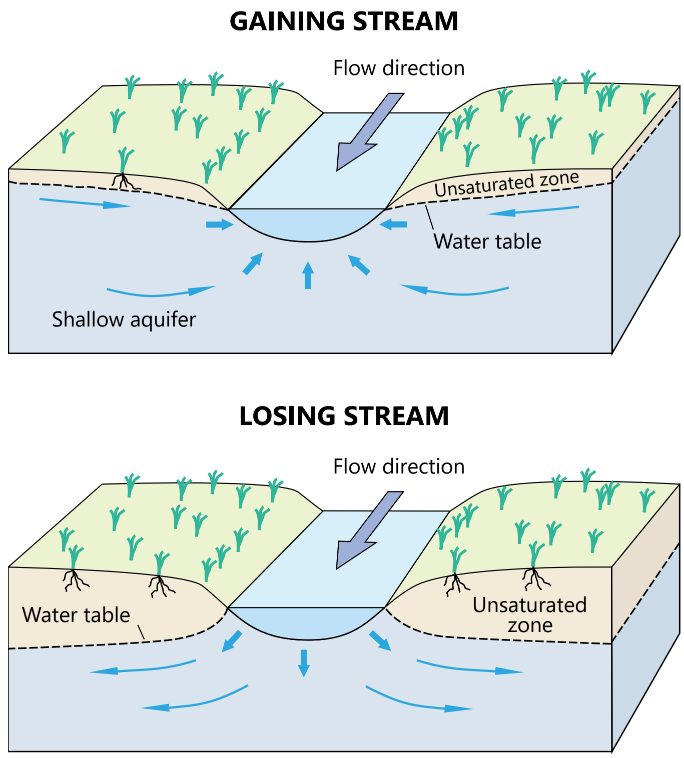
Other Surface-Water Features

Although Nagawicka Lake, the Upper Bark River, and streams tributary to the Lake and River were the primary focus of this study, other significant water resource features exist in the Nagawicka Lake watershed. These features include lakes, ponds, wetlands, and floodplains. Such features can detain stormwater runoff and enhance water quality. More information about these features is presented in this section.

Natural lakes and ponds are found throughout the Nagawicka Lake watershed. Five named natural lakes are present near the headwater area of the Bark River. In addition to natural lakes, dozens of artificial ponds dot the Lake's watershed. These artificial ponds were either built to provide an aesthetically pleasing feature or foster wildlife or are the result of other activities such as gravel mining. Table 2.7 summarizes the characteristics of prominent lakes and ponds in the Lake's watershed.

Wetlands are by far most prevalent in the low gradient headwater reaches of the Upper Bark River. Wetlands are commonly found along waterbodies in locations that periodically flood. The definition of what legally constitutes a wetland or floodplain is a regulatory matter, and is discussed in more detail in the "Jurisdictional Roles and Responsibilities" subsection of Section 2.1, "Physiography and Cultural Geography."

Figure 2.7
Surface-Water/Groundwater Interaction



Source: Modified from T.C. Winter, J.W. Harvey, O.L. Franke, and W.M. Alley, Ground Water and Surface Water: A Single Resource, *U.S. Geological Survey Circular 1139, p. 9, 1998, and SEWRPC*

Groundwater

General Principles and Importance

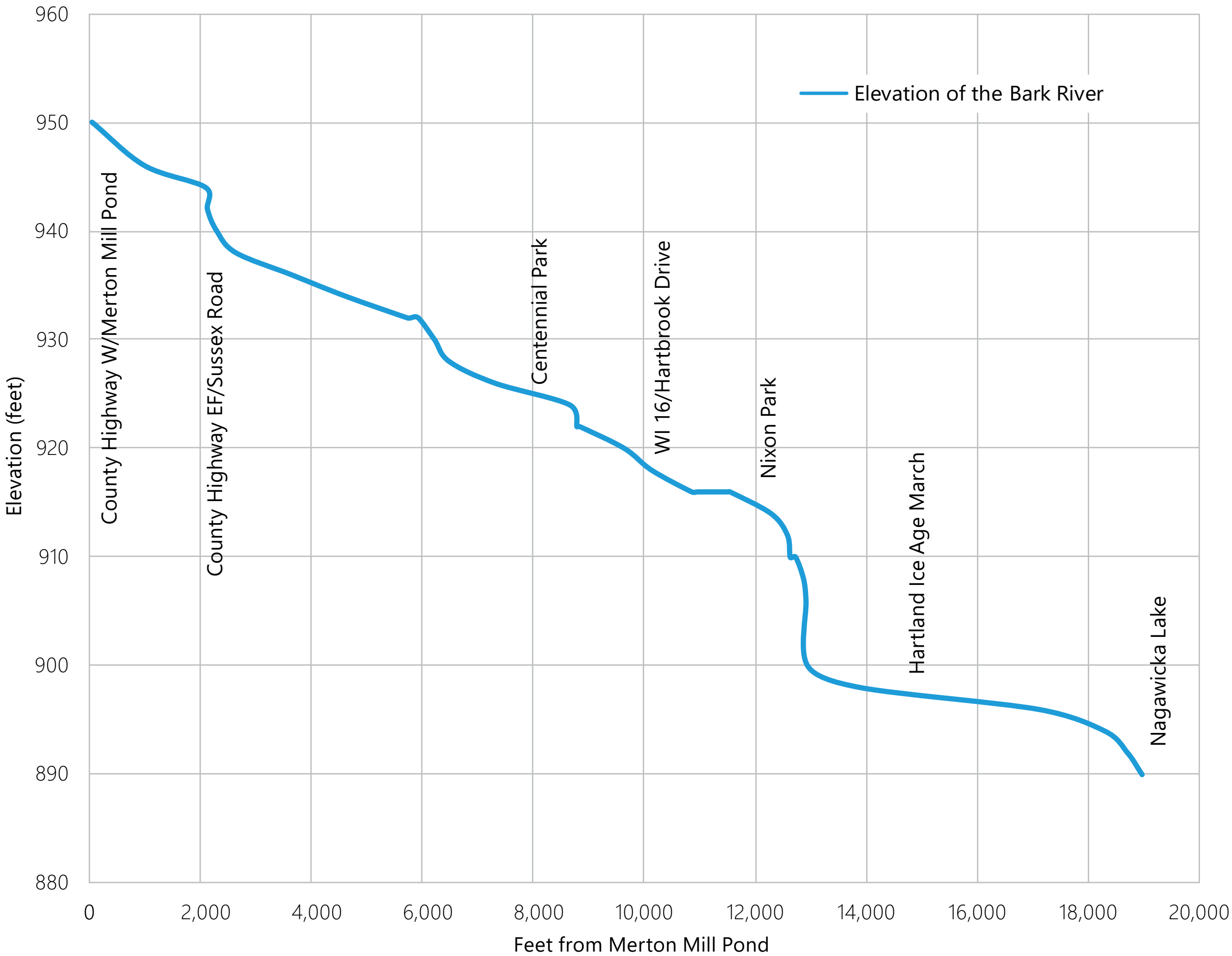
Groundwater includes water that has percolated into the earth and has reached areas of saturation below the Earth's surface. The free-water elevation of the shallowest saturated subsurface water-bearing media is commonly referred to as the "water table". Groundwater is not visible to casual observation except where it discharges to surface water (e.g., springs and seeps). Water in unsaturated soil above the water table can either return to the atmosphere via evapotranspiration or may move to aquifers if soil moisture increases through additional percolation from the surface.

In Southeastern Wisconsin, local precipitation is the source of most groundwater and essentially all groundwater is stored and moves in the natural pore spaces and fractures found in unconsolidated sediment and bedrock.[34] Sediment and rock units with significant porosity or fracturing are able to supply useable amounts of water over prolonged periods, and are referred to as "aquifers." Three aquifers underlie the Nagawicka Lake watershed, as summarized below in order of increasing depth from the land surface.

- **Sand and gravel aquifer.** This aquifer is primarily found in porous, coarse-grained sand and gravel deposited by glacial action. Much of the water feeding this aquifer infiltrates the land surface in the local area. Its thickness and properties vary widely, but it is an important water supply under many portions of Waukesha County. It is commonly highly vulnerable to contamination and over exploitation. Water quality and quantity can be significantly influenced by local land use change.

[34] *A common local myth suggests that water flows in underground rivers from the far north (e.g., Lake Superior). Although a few small caves are found in Southeastern Wisconsin, they are not significant contributors to overall groundwater flow and do not extend appreciable distances.*

Figure 2.8
Longitudinal Bark River Bed Profile Downstream of Merton Millpond



Source: U.S. Geological Survey and SEWRPC

The sand and gravel aquifer is commonly in good hydraulic communication with the underlying Niagara dolomite aquifer.

- **Niagara dolomite aquifer.** Water in this aquifer is stored and moves primarily in fractures. Much of the water found in this aquifer is derived from local stormwater infiltration. The water-bearing characteristics and thickness of this aquifer vary widely. Although it is absent in portions of the watershed, when present, it is an important water supply aquifer. When located under a relatively thick layer of unconsolidated sediment, it is somewhat less vulnerable to contamination and overexploitation.

- **Sandstone aquifer.** The sandstone aquifer is deeply buried under much of central and eastern Waukesha County below the sand and gravel and Niagara dolomite aquifers. Water is stored and moves through fractures and the rocks' intrinsic porosity. This aquifer is very thick, but the water bearing characteristics vary widely between the various rock layers composing this aquifer. A layer of low permeability shale overlies the sandstone throughout entire Nagawicka Lake watershed. Therefore, most water recharging the sandstone aquifer infiltrates the ground west of the Nagawicka Lake watershed where the shale layer is absent. For this reason, the sandstone aquifer is less vulnerable to local pollution sources in the Nagawicka Lake watershed. The sandstone aquifer is an important public and industrial water supply, but because of the cost of establishing deep wells, is not commonly used for residential water supplies in the immediate area.

The amount, recharge, movement, and discharge of groundwater are controlled by several factors including precipitation, topography, soil permeability and structure, land use, and the lithology and water-bearing properties of rock units.

All residential, municipal, and industrial water supplies in the Nagawicka Lake watershed depend upon groundwater, making it a natural resource critical to human habitation. In general, groundwater supplies in the Region are adequate to support a growing population, agricultural demands, commerce, and viable and diverse industrial uses. However, overexploitation and attendant water shortages could occur in areas of concentrated development, nonconductive geology, and/or intensive water demand. In addition to supplying human needs, groundwater is important to the health, vitality, and overall ecology of natural systems. Groundwater sustains water levels and flow in lakes, wetlands, and perennial streams during dry weather. Groundwater systems also modulate flood flows by detaining water during wet weather. Groundwater that reaches surface waterbodies is commonly referred to as “baseflow”. Baseflow can either directly enter large waterbodies, or it can enter small streams, ponds, and seeps tributary to larger waterbodies. Growing population and industry while maintaining vitality of valuable natural resource elements necessitates wisely developing and managing groundwater resources.

Baseflow sustains dry-weather Lake elevation and the flow of the perennial tributary streams. Groundwater typically contains little to no sediment or phosphorus, has a more stable temperature regimen, and commonly contains a lower overall pollutant load when compared to surface water runoff – all of which are favorable to aquatic life and the ecology of waterbodies. Groundwater-derived baseflow sustains water elevations and/or flow in many lakes, wetlands, and streams during drier weather periods. Reliable water elevations and flow regimens enables groundwater-fed waterbodies to maintain a diverse assemblage of plants and animals. Groundwater is critical to these waterbodies’ ability to provide unique ecological functions. Consequently, it is important to maintain baseflow from the aquifers that supply Nagawicka Lake and the streams and wetlands that drain to the Lake.

Figure 2.9
Bark River Downstream of Merton Millpond: 2016

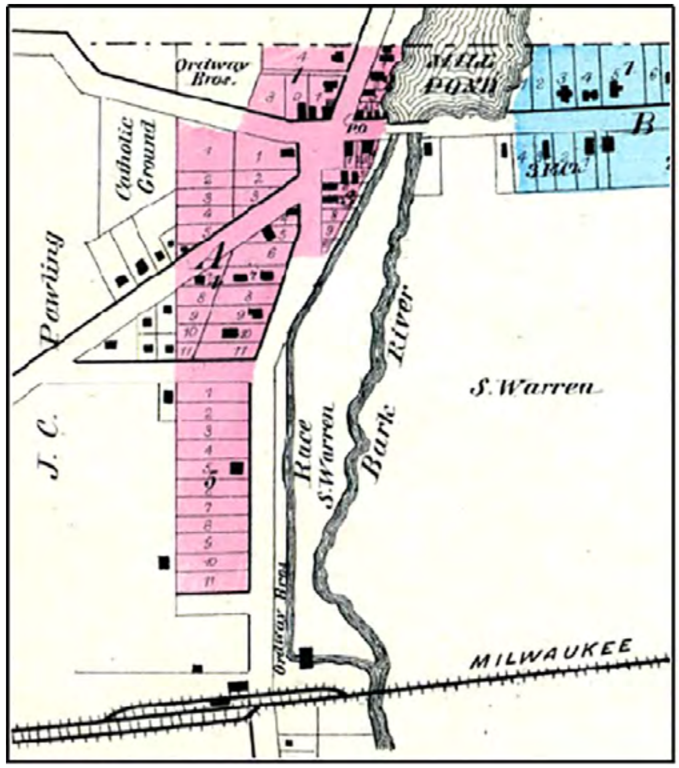
Source: SEWRPC

Figure 2.10
Merton Rolling Mill Dam: 2016

Source: SEWRPC

Groundwater is replenished by precipitation that soaks into the ground and enters aquifers, often referred to as "groundwater recharge". Groundwater recharge is highly dependent upon land surface topography, runoff patterns, soil characteristics, precipitation patterns, vegetation, and the permeability of the land surface. For example, a flat area with no impervious cover and highly permeable soils likely has high or very high groundwater recharge potential, whereas a hilly area underlain with low permeability (e.g., clay) soils and drained by storm sewers would be classified as low potential. Evaluating groundwater recharge potential helps identify areas most important to sustainable groundwater supplies. The Commission evaluated groundwater recharge potential for all of Southeastern Wisconsin. Such data can help planners decide which areas should not be covered with impervious surfaces in the surface and/or where infiltration basins would be most effective.

Figure 2.11
Location and Layout of Former Hartland Dam



Source: Harrison and Warner, Plat Map of Waukesha, Hartland and Sussex, Waukesha County, Wisconsin, 1873

In most instances, the elevation of the water table is a subdued reflection of surface topography. Topographically higher areas are commonly recharge areas, while lakes, wetlands, and streams are commonly groundwater discharge areas. Groundwater recharge/discharge systems occur on many spatial scales: long regional recharge/discharge relationships and short localized flow paths, both of which can be important contributors to a water body's overall water budget. While localized groundwater flow systems are commonly confined within a lake's surface watershed, regional groundwater flow paths may trace directions and distances out of phase with surface water feeding a lake. Therefore, some groundwater feeding a lake may originate in areas distant from the lake and/or outside the lake's surface watershed boundary. The relationship between short- and long-distance flow paths is illustrated in Figure 2.13.

Smaller-scale local groundwater flow paths commonly approximate surface water flow paths. However, to estimate the direction of more regionally extensive flow systems, groundwater elevation contours derived from measurements collected in water supply or monitoring wells need to be consulted. Since water normally moves perpendicular to elevation contours, groundwater flow directions can be predicted. When performing such analysis, it is necessary to consider the locations and elevations of streams, ponds, and lakes. This relationship can be used to predict if a surface water body is fed by groundwater, recharges groundwater, or has little interaction with groundwater. By combining these data, maps can be prepared identifying those land areas that likely contribute recharge and are, therefore, sources of baseflow to a surface water feature and those areas that convey groundwater directly to a lake.

As illustrated in Figure 2.7, groundwater and surface water systems are connected. Water sources include:

- **Precipitation** falling directly upon a water body. While this can be a significant water source to expansive features such as lakes and wetlands, it typically is not a significant contributor to a stream or river's total water budget
- **Surface runoff** (or overland flow) that travels over the land surface to a waterbody. Surface runoff is the primary source of wet-weather flow to most watersheds.

Table 2.4
Nagawicka Lake Watershed Sub-Basin Characteristics

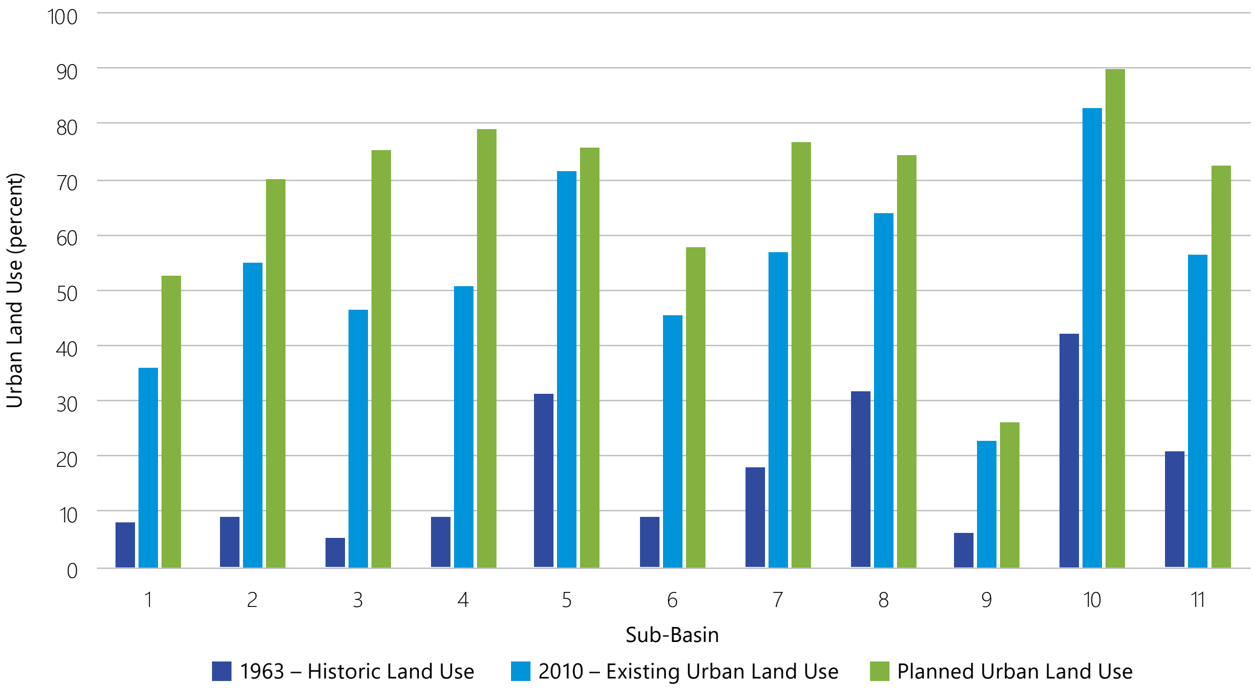
Sub-Basin Number	Acres	Percent of Upper Bark River or Lake-Direct Watershed	Description
Upper Bark River Sub-Basins			
1	16,326	69	All areas upstream of Village of Merton dam. Fifteen mapped first-order tributaries. Twelve are perennial and three are intermittent. Partially developed, much at low intensity without apparent significant stormwater infrastructure. Scattered Ten tributaries enter river right, the remaining five enter river left.[a]
2	1,025	4	Partially developed River direct drainage area downstream of Merton dam and upstream of first mapped tributary. Significant proportion of the area served by a mix of pre- and post-1990 stormwater infrastructure. No mapped tributaries.
3	1,888	8	Partially developed drainage basin of mapped intermittent, second-order, left tributary just upstream of the Village of Hartland. Significant proportion of the developed area drained mostly by post-1990 stormwater infrastructure. Some developed areas served by pre-1990 stormwater infrastructure.
4	934	4	Urbanizing River direct drainage area upstream of Village of Hartland and downstream of sub-basin 3. Significant proportion of the area served by post-1990 stormwater infrastructure, modest proportion served by pre-1990 stormwater infrastructure. No mapped tributary streams.
5	1,515	6	Largely developed River direct drainage area roughly equivalent to the Village of Hartland. No mapped tributaries. Sizeable proportion of the area is served by pre-1990 stormwater infrastructure. Stormwater BMPs implemented in some pre-1990 stormwater infrastructure areas.
6	1,847	8	Partially developed River direct drainage area mostly downstream of the Village of Hartland and upstream of Nagawicka Lake. Substantial proportion of the area served by pre-1990 and post-1990 stormwater infrastructure. Stormwater BMPs implemented in some pre-1990 stormwater infrastructure areas. One small, mapped, perennial, first-order, left tributary.
Total 1-6	23,534[b]	100[b]	Entire Upper Bark River watershed.
Nagawicka Lake-Direct Sub-Basins			
7	1,003	20	East-central shoreline, immediately south of Bark River. Large areas developed prior to 1990. Except for far eastern periphery which is an industrial area, little apparent stormwater infrastructure. No mapped tributaries.
8	1,020	20	Drains areas immediately southeast of the Lake, including the large commercial area at the intersection of STH 83 and IH 94. Extensively developed, most areas before 1990. Some stormwater BMPs installed in pre-1990 stormwater infrastructure areas.
9	1,264	25	Drains area immediately southwest of the Lake and extending a considerable distance beyond IH 94. Undeveloped except near Lake. Most developed occurred before 1990. No known stormwater infrastructure.
10	721	14	Drains a portion of the City of Delafield. Mostly developed before 1990, a few areas retrofitted with stormwater BMPs. Limited apparent stormwater infrastructure.
11	1,115	22	Drains all areas tributary to the north end of the Lake, excluding the Bark River. Partially developed, about half of development occurring before 1990. Limited apparent stormwater infrastructure.
Total 7-11	5,122[b]	100[b]	Entire Lake-direct watershed.

[a] *Perennial streams generally flow all year, while intermittent streams commonly cease flowing during drier weather. River left/right is defined looking downstream. For example, when looking downstream, a "river right" tributary enters from the right-hand side.*

[b] *Rounding in individual sub basin values creates a 1 acre discrepancy.*

Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.12
Historic (1963), Existing (2010), and Planned Urban Land Use Within Nagawicka Lake Watershed Sub-Basins



Source: SEWRPC

Table 2.5
Nagawicka Lake Surface Water Sources

Identity	Acres	Probable Annual Water Contribution to Nagawicka Lake (acre-feet/year)		
		Dry Years	Average Years	Wet Years
Bark River (Sub-Basins 1, 2, 3, 4, 5, 6)	23,534	13,400	21,700	28,600
Southeast Lake-Direct (Sub-Basin 8)	1,020	149	241	317
Southwest Lake-Direct (Sub-Basin 9)	1,264	430	696	917
Remaining Lake-Direct (Sub-Basins 7, 10, and 11)	2,838	661	1,070	1,410
Total	28,656	14,600[a]	23,700[a]	31,200[a]

[a] *Totals are rounded resulted in a slight discrepancy.*

Source: U.S. Geological Survey and SEWRPC

Table 2.6
Nagawicka Lake Watershed Water Yield Estimates

Identity	Acres	Probable Annual Water Yield (inches/year)		
		Dry Years	Average Years	Wet Years
Bark River (Sub-Basins 1, 2, 3, 4, 5, 6)	23,534	6.8	11.1	14.6
Southeast Lake-Direct (Sub-Basin 8)	1,020	1.7	2.8	3.7
Southwest Lake-Direct (Sub-Basin 9)	1,264	4.1	6.6	8.7
Remaining Lake-Direct (Sub-Basins 7, 10, and 11)	2,838	2.8	4.5	6.0
Total	28,656	--	--	--

Source: U.S. Geological Survey and SEWRPC

Table 2.7
Prominent Lakes and Ponds in the Nagawicka Lake Watershed

Name	Sub-Basin of Occurrence	Size (acres)	Maximum Depth (feet)	Origin	Probable Hydrology
Lake Five	1	104	23	Natural	Seepage
Bark Lake	1	65	32	Natural	Drainage
Amy Bell	1	30	37	Natural	Seepage
Mud	1	6.8	6	Natural	Seepage or Spring
Unnamed	6	2.1	Unknown (Likely Shallow)	Natural	Unknown
Unnamed	9	6.6	Unknown (Likely Shallow)	Natural	Drainage
Merton Millpond	1	38	8	Artificial – Reservoir	Drainage
Unnamed	1	28	Unknown	Artificial – Former Aggregate Mining Operation	Seepage
Unnamed	1	15	Unknown	Artificial – Former Aggregate Mining Operation	Seepage
Unnamed	5	2.8	Unknown	Artificial – Landscaping Element	Unknown

Source: Wisconsin Department of Natural Resources, Waukesha County, and SEWPC

- **Hyporheic flow** (stream flow occurring in stream bed materials paralleling the general direction of stream flow). This is only important in streams and rivers. Hyporheic flow commonly persists even when visible stream flow ceases. Hyporheic flow initiates and sustains a large number of important geochemical and biological processes that support stream health.

- **Groundwater** is the primary source of water to most waterbodies during dry weather. In some instances, waterbodies lose water to the groundwater flow system.

Surface runoff and interflow are important during storm events, and their contributions typically are combined into a single term called the direct runoff component of streamflow. Groundwater, on the other hand, is most important for sustaining waterbodies during periods between storms and during dry times of the year and is often a substantial component of the total annual flow through a waterbody.

As shown in Figure 2.7, a waterbody gains water when groundwater elevations are higher than the adjacent waterbody. Conversely, a perennial waterbody loses water wherever water table elevation is lower than the waterbody's elevation. In such instances, water seeps into the underlying groundwater system. In some instances (e.g., ephemeral streams) the water table may not be in contact with the surface water feature. Stream reaches that receive groundwater discharge are called gaining reaches and those that lose water to the underlying aquifer are called losing reaches. The rate at which water flows between a stream and its adjoining aquifer depends on the hydraulic gradient between the two waterbodies and also on the hydraulic conductivity of geologic materials that may be located at the groundwater/surface-water interface. For example, a clayey streambed will reduce the rate of flow between a stream and aquifer compared to a sandy or gravelly streambed. In the absence of surface-water contributions, streamflow volume increases along gaining reaches and decreases along losing reaches. Streams can have both gaining and losing reaches and the extent of these reaches may change based upon prevailing conditions. Since precipitation rates, evapotranspiration, water table elevations, and human-induced hydrologic stressors vary with time, a particular stream reach can switch from a gaining to a losing condition or from a losing to a gaining condition from one period of time to the next.

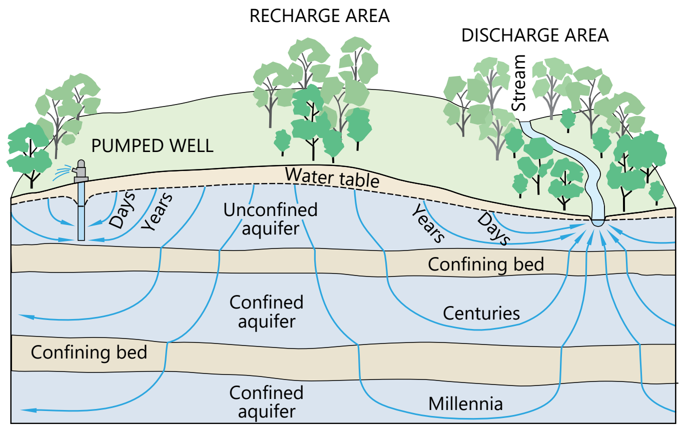
Groundwater is a dynamic resource. Water discharging to water bodies is replaced with water infiltrating in recharge areas. By combining data regarding recharge potential, groundwater flow direction, and the elevation of water bodies, a broad understanding of the interconnected nature of surface water and groundwater can be surmised. Maps can be prepared identifying land areas that likely contribute recharge and are, therefore, sources of baseflow to a waterbody; areas that convey groundwater to the waterbody; and whether a waterbody gains or loses water to the groundwater flow system. This helps managers plan where work should be focused to maintain or enhance the landscape's ability to sustain groundwater supplies as well as where features purposely designed to detain and infiltrate stormwater are most desirable.

Human Influence

Development's Effects on Groundwater

Land use can profoundly alter the ability for an area to absorb water and contribute to groundwater recharge. Urban development decreases groundwater recharge potential. Most areas developed earlier than 30 years ago route stormwater runoff directly to surface waters, discouraging groundwater recharge. Despite requirements of Chapter NR 151, "Runoff Management," of the *Wisconsin Administrative Code* calling to detain/infiltrate runoff from new developments, where practicable, such developments still have the cumulative effect of reducing groundwater recharge compared to pre-development conditions. In addition to reducing groundwater recharge, urban development places additional demand on groundwater supplies as water is extracted for various uses. Removing water from natural groundwater flowpaths reduces groundwater elevations and the volume of natural groundwater discharge to surface waterbodies.

Figure 2.13
Groundwater Flow Paths in a Multi-Aquifer Groundwater System



Groundwater flows from recharge areas at the water table to discharge locations at the stream and well. The residence time of groundwater can range from days to centuries to millennia.

Source: U.S. Geological Survey and SEWRPC

Wells developed in the shallow aquifer often provide sufficient yield, but can negatively impact nearby surface water resources, and are generally more vulnerable to contamination than deeper bedrock wells. Communities tapping the shallow aquifer also face choices between using individual low-capacity household wells or developing a municipal water system with homeowners connecting to high-capacity municipal wells. In some cases, these communities have an overall negative groundwater balance because wastewater treatment plant effluent is pumped to discharge points outside of the watershed. In cases where development of high capacity wells in the shallow aquifer could negatively affect surface water resources, the Commission's regional water supply plan recommends conducting studies to evaluate the potential negative effects.[35] The plan also calls for installing systems to enhance infiltration in areas where such studies indicate a potential significant reduction in baseflow to surface waters.

Waterbody Depletion

Although groundwater generally provides a safe and reliable source of potable water, groundwater extraction can seriously and adversely affect desirable, life-cycle critical, aquatic habitat. One of the most visible effects is reduced dry-weather flow and water levels in hydraulically connected lakes and streams—a process called depletion. Depletion stems from reduced discharge to springs and seeps feeding these waterbodies and has the potential to impact lakes, ponds, streams, rivers, and wetlands. The complex interconnection and interaction between surface and groundwater makes managing depletion challenging, particularly because significant delays may occur from the time when extraction begins to the time when the effects of that extraction are discerned in affected waterbodies. Other complicating factors may confound analysis and influence the timing, rate, and location of depletion. Nonetheless, managers should keep in mind several important factors when studying the relationship between surface-water features and groundwater pumping, including the following:

- Individual wells may not produce noticeable change. However, well clusters and/or unfavorable aquifer properties can combine to significantly decrease groundwater discharge to surface-water features.

- Basin-wide groundwater development typically occurs over a period of several decades. Therefore, resulting cumulative depletion effects may not manifest themselves for decades.

[35] *SEWRPC Planning Report No. 52,* A Regional Water Supply Plan for Southeastern Wisconsin*, December 2010.*

- Depletion may persist for extended periods of time after groundwater withdrawal ends. Aquifers take time to recover from long-term extraction stress. In some aquifers, maximum depletion may occur long after pumping stops, and full recovery of the groundwater system may take decades to centuries.

- Depletion can affect water quality in surface-water features and/or the aquifer. For example, in many streams, groundwater discharge sustains year-round habitat for fish and other aquatic organisms. For example, groundwater discharge moderates seasonal temperature fluctuations, cooling stream temperatures in summer and warming stream temperatures in winter. Reduced groundwater discharge can degrade these moderating influences.

- Major factors affecting depletion timing and intensity are distance from a well to the stream and aquifer properties.

- Decreased discharge may focus on certain waterbodies or may be pervasive throughout the area.

Sustainable groundwater utilization does not solely depend on the rates at which groundwater systems are naturally replenished (recharged). Instead, sustainable pumping rates must consider myriad factors including aquifer properties, groundwater elevations, surface-water features, biologically acceptable minimum stream flows, and the wishes of the general public and regulatory agencies. These considerations underscore the need to employ an interdisciplinary approach that concomitantly considers both surface-water features and groundwater supplies.

An example of unsustainable groundwater use is extraction from the deep sandstone aquifer. Water levels in the deep sandstone aquifer were once above the ground surface, meaning that water rose to above the ground without pumping. The quality and abundance of this resource made it a prime target for large volume well. On account of heavy withdrawals throughout the region, this aquifer's water levels have declined hundreds of feet since the 1800s, as shown in Figure 2.14. In much of the Region, including the Bark River watershed, water movement from the shallow sand and gravel and dolomite aquifer into the deep sandstone aquifer is limited by the low permeability Maquoketa shale aquitard, a rock layer which forms a relatively impermeable barrier between the two aquifers and direct surface recharge. As a result, the rates of local groundwater recharge to the deep aquifer are much less than the rates that water is being extracted by pumping. The drawdowns of the deep aquifer are indicative of a water budget deficit and are the combined result of pumping primarily in Southeastern Wisconsin and Northeastern Illinois. In contrast, drawdowns in the shallow aquifer throughout the Region are much smaller (see Figure 2.14) despite the fact that nearly twice the amount of water is being extracted from it compared to the deep aquifer. The reason for the lower drawdowns is that the shallow aquifer is unconfined in most places. It receives direct recharge from precipitation and is also linked directly to surface waterbodies as illustrated in Figure 2.15 above.

Management Tools – Plans and Models

The Commission developed a water supply system plan for the Southeastern Wisconsin Region.[36] This plan considers existing water demands, future development, sustainability, and protection of natural resource features. This plan is the third component of the Commission's regional water supply planning program. The other two elements were a groundwater resource inventory and a regional groundwater.[37,38] The regional aquifer simulation model allows water levels in the deep and shallow aquifers under historical, current, and planned condition to be predicted and allows the effects of different groundwater management alternatives on surface water resources to be simulated. Additionally, the model provides a framework within which more-detailed "inset" models may be developed to investigate site-specific groundwater-related questions, including the possible effects of high capacity wells on surface water resources. In summary, the model provides the capability of addressing the following questions:

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[36] *Ibid.*

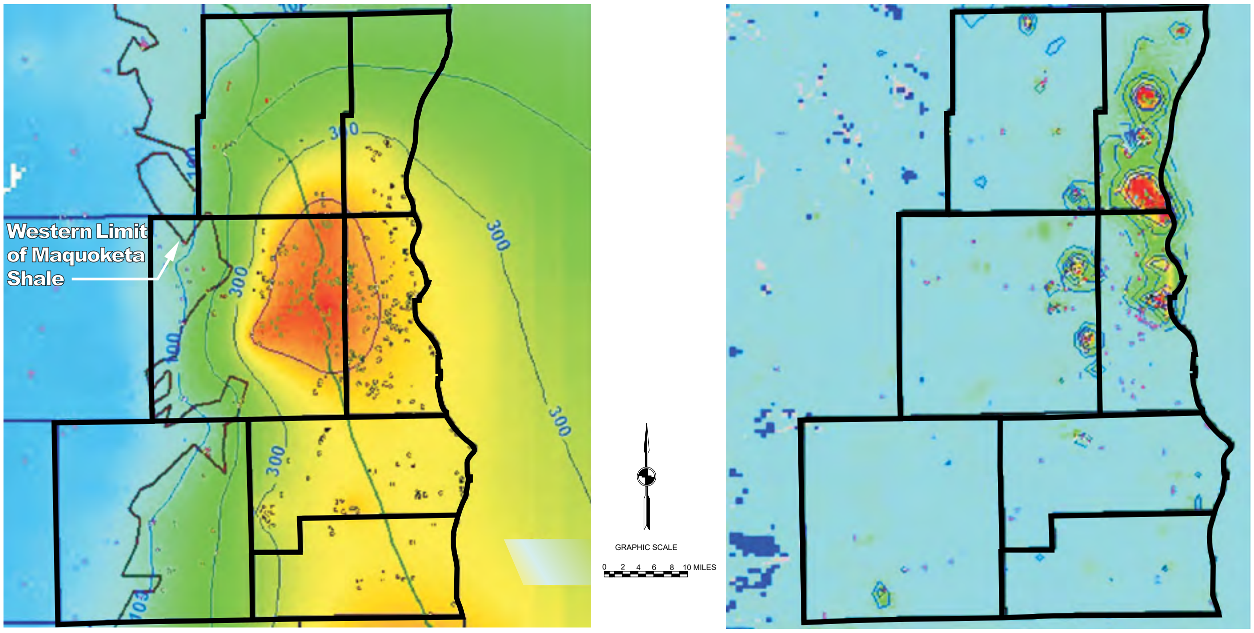
[37] *Southeastern Wisconsin Regional Planning Commission Technical Report Number 37,* Groundwater Resources of Southeastern Wisconsin*, June 2002.*

[38] *Southeastern Wisconsin Regional Planning Commission Technical Report Number 37,* A Regional Aquifer Simulation Model for Southeastern Wisconsin*, June 2005.*

Figure 2.14
Simulated Groundwater Drawdowns for the Region: 2000

Figure A: Deep Aquifer – the red zones shows areas where pumping has depressed natural groundwater pressure head by more than 400 feet. In many areas, the deep aquifer naturally had pressure sufficient to produce artesian conditions.

Figure B: Shallow Aquifer – the red zones are areas where pumping has depressed the water table by more than 50 feet.



Source: U.S. Geological Survey, Wisconsin Geological and Natural History Survey, and SEWRPC Technical Report No. 46, Groundwater Budget Indices and Their Use in Assessing Water Supply Plans for Southeastern Wisconsin, *February 2010*

- What is the sustainable capacity of an aquifer to supply human needs?
- How much have humans altered the groundwater system?
- What effect does human groundwater system alteration have on surface waters?

It is important to note that while the resolution of the regional groundwater models was considered sufficient and valid to compare differences alternative plans, it may not be sufficiently fine to predict site-specific impacts, or may not be able to resolve differences in impacts between surface water or groundwater features that are in close proximity to one another.[39] Simulating condition over a relatively small areas such as the Nagawicka Lake watershed would require a refined model that includes more detailed site-specific hydrogeological data and smaller model cell size. As noted previously, in cases where development of high capacity wells in the shallow aquifer could negatively affect surface water resources, the Commission's regional water supply plan recommends detailed site-specific conducting studies to evaluate potential negative effects and installing enhanced rainfall infiltration systems in areas where such studies indicate a potential significant reduction in baseflow to surface waters.

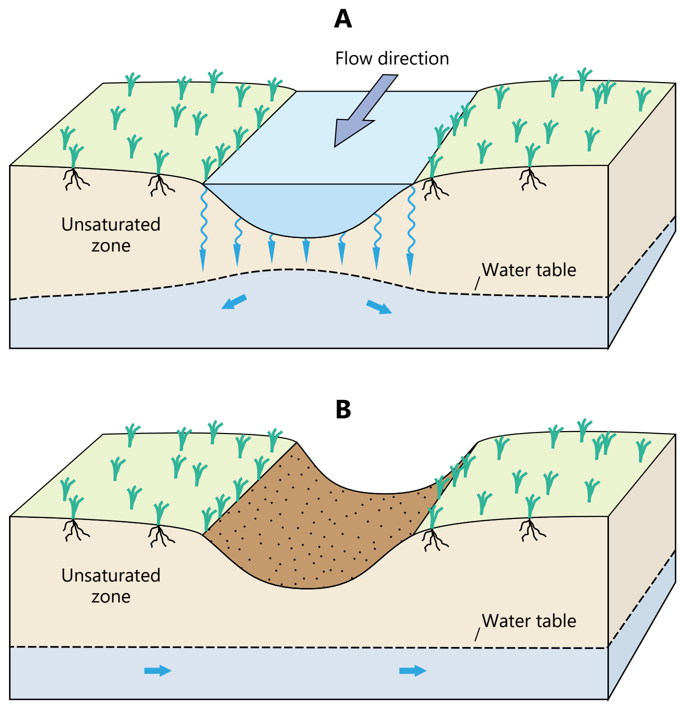
One of the most accessible and effective tools developed as part of the water supply planning effort is the groundwater recharge potential map derived from a soil-water balance recharge model developed for the Southeastern Wisconsin Region. Understanding groundwater recharge potential and its distribution on the landscape are key to making informed land use decisions that jointly consider human and environmental groundwater needs. Unlike the regional model discussed above, groundwater recharge potential maps are

[39] *Since the average grid cell size of the groundwater simulation model is over one-quarter square mile (about 2,500 feet on a side), the results from this regional modeling effort are not sufficiently detailed to evaluate the impact of groundwater withdrawal on a site-specific basis. In other words, this regional model cannot specifically be used for local level groundwater supply planning purposes for the Nagawicka Lake watershed, because this area is too small.*

plotted at a significantly smaller grid size (about 100 feet on a side) and can therefore be directly employed for local level groundwater planning purposes. Therefore, these groundwater recharge potential maps are generally applicable to the Nagawicka Lake watershed for identifying and protecting recharge areas that contribute most to baseflow of the lakes, streams, springs, and wetlands in the watershed, which is important to the goals of sustainable groundwater use and a healthy natural environment.

In summary, sustainable groundwater supplies provide reliable, high-quality water that supports both short-term and long-term needs and desires. Reliable water supplies support existing and new development avoid undue influence on existing wells and natural groundwater discharge areas and avoid reduced groundwater discharge or adulterated quality that could affect treasured and sensitive natural resource features.

Figure 2.15
Groundwater and Streamflow Interactions: Hydraulically Disconnected Stream Reaches



Disconnected stream reaches are separated from the groundwater system by an unsaturated zone. In other words, the water table is lower than the streambed. In A, streamflow is a source of recharge to the underlying groundwater system, but in B, streamflow and groundwater recharge have ceased and the streambed is dry.

Source: U.S. Geological Survey and SEWRPC

<u>Groundwater Conditions in the Nagawicka Lake Watershed</u>

A variety of data sources exist that help quantify groundwater conditions in the Nagawicka Lake watershed. Water table elevation and groundwater recharge potential maps are available for the entire watershed.[40] Additionally, the USGS installed and collected data in several monitoring wells near the Lake.[41] These data sources were used to estimate the area in which infiltrating surface water eventually enters the Nagawicka Lake watershed, quantify the relative potential for surface water to infiltrate the ground surface and become a component of groundwater flow, identify general groundwater flow directions, and describe the interaction of waterbodies with the groundwater flow system.

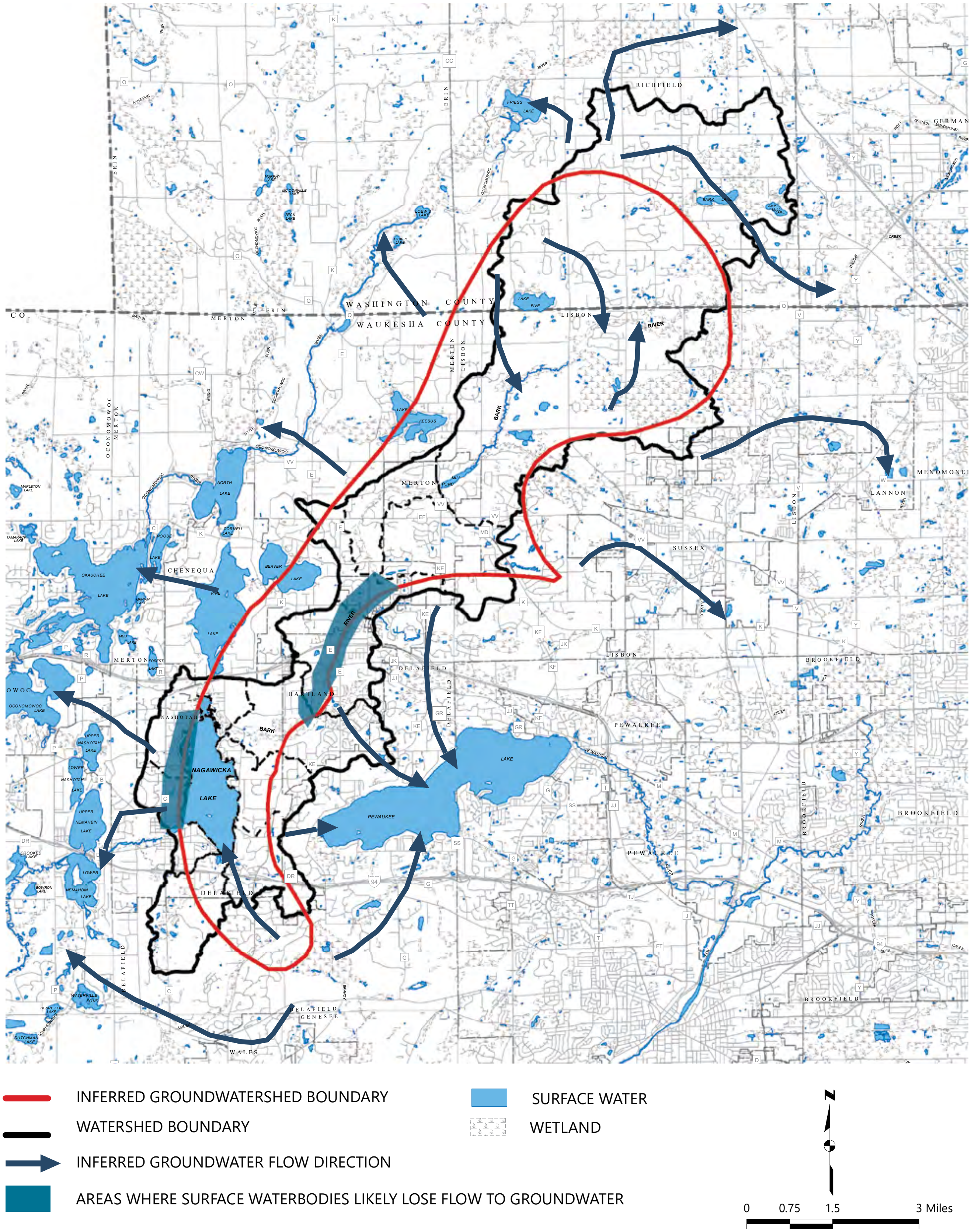
Water table elevation contours were used to estimate the extent of the shallow groundwatershed and groundwater flow direction (see Map 2.12). Under natural conditions, surface water percolating into the ground within this area eventually discharges to Nagawicka Lake, the Bark River, and other tributary streams. The Nagawicka Lake groundwatershed is roughly the same size as the area contributing surface water to the Lake and River. However, groundwater under large swaths of the surface-watershed does not ultimately discharge to surface-waterbodies in the Nagawicka Lake watershed. This includes the extreme headwater reaches of the Bark River and much of the eastern portion of the Village of Hartland. Water infiltrating into soils in these areas joins groundwater flowpaths terminating in the Menomonee and Fox Rivers. The groundwatershed feeding Nagawicka Lake does extend west beyond the Bark River watershed into an area under the western periphery of the Oconomowoc River watershed. This means that some of the groundwater feeding the Bark River percolates into soils in the Oconomowoc River watershed.

Most waterbodies in the Nagawicka Lake watershed receive water from the groundwater flow system. As was mentioned above, the Bark River just upstream of the Village of Merton is likely to gain considerable flow from groundwater sources. However, somewhat unusually for Southeastern Wisconsin, the Bark River

[40] *SEWRPC Technical Report No. 37,* Groundwater Resources of Southeastern Wisconsin, *June 2002 and SEWRPC Technical Report No. 47,* Groundwater Recharge in Southeastern Wisconsin Estimated by a GIS-Based Water-Balance Method, *July 2008.*

[41] *Garn, 2006*, op. cit.

Map 2.12
Inferred Groundwater Flow Direction in and Near the Nagawicka Lake Watershed



Source: SEWRPC

appears to lose flow to the groundwater in the Village of Hartland reach. A portion of the River's flow likely infiltrates into its bed. Some of this infiltrating River water re-emerges in the Nagawicka Lake watershed. However, much of the infiltrating River water feeds groundwater flow systems terminating in Coco Creek (a tributary to Pewaukee Lake) and Pewaukee Lake. Similarly, Nagawicka Lake appears to lose water through its bed along much of the Lake's western shoreline to the north of the Lake's outlet.

The groundwater recharge potential in and near the Nagawicka Lake watershed is also mapped on Map 2.13. Groundwater recharge potential is divided into four categories: low, moderate, high, and very high. Any areas that were not defined were placed into a fifth category (undefined). Undefined areas are often associated with groundwater discharge areas, which is why they tend to be located adjacent to streams. The most extensive tracts of "very high" and "high" groundwater recharge potential occur in sub-basin 1, immediately upstream of the Village of Merton. This suggests that the reach of the Bark River just upstream of the Village of Merton likely is a key contributor to dry-weather flow in the River and ultimately the Lake. This finding is supported by the numerous springs mapped in this section of the River.[42]

Modest areas of high groundwater recharge potential occur between the Village of Merton and the northern fringe of the Village of Hartland. Aside from limited areas south of the Lake, comparatively few very high and high groundwater recharge potential areas are found within and downstream of the Village of Hartland and around Nagawicka Lake.

Preserving and enhancing the recharge potential within the groundwatershed upstream of Hartland and downstream of the Washington-Waukesha County line is essential to protecting the baseflow of the Bark River and the Lake. Areas with very high and high groundwater recharge potential anywhere within the more developed southern portion of the watershed are ideal sites to position stormwater infrastructure designed to infiltrate detained stormwater.[43] Infiltrating stormwater helps reduce peak flows and increases cool, high quality, baseflow to waterbodies during dry periods, conditions that generally improve waterbody health.

All water used by humans in the watershed is supplied by groundwater, and most is drawn from shallow aquifers. In addition to the residential wells supplying potable water for homes, high capacity wells withdraw groundwater throughout the watershed. For example, the Village of Hartland pumped an average of over 1,000,000 gallons per day during 2005. At that time, the Village pumped water from four wells, some drawing from sand and gravel, and some drawing from the sandstone aquifer. In addition to the Village of Hartland's wells, privately owned high capacity wells draw water for commercial and residential use.

Water supply within the watershed may be threatened by loss of valuable recharge sites and overdrawing by sanitary sewers. As of 2010, about one-third of the Nagawicka Lake watershed was either served or was planned to be served by public sewers (see Map 2.14). These areas are overwhelmingly concentrated downstream of the Village of Merton. Several sub-basins are, or are planned to be, completely served by public sanitary sewers. All wastewater discharged to public sanitary sewers is exported from the watershed. Since the water discharged to sanitary sewers originates as groundwater drawn from within the watershed, human water use in areas served by public wastewater collection systems represents a significant net artificial demand placed upon the groundwater flow system feeding waterbodies in the Nagawicka Lake watershed. That demand decreases groundwater discharge to the watershed's waterbodies. Aquifer simulation modeling conducted under the Commission's regional water supply plan indicates that, under year 2035 recommended land use and water supply conditions and in the absence of enhanced infiltration of stormwater in the watershed, baseflow to Nagawicka Lake could be reduced by 10 to 25 percent compared to year 2005 conditions. This emphasizes the importance of maintaining and enhancing recharge to the shallow sand and gravel aquifer.

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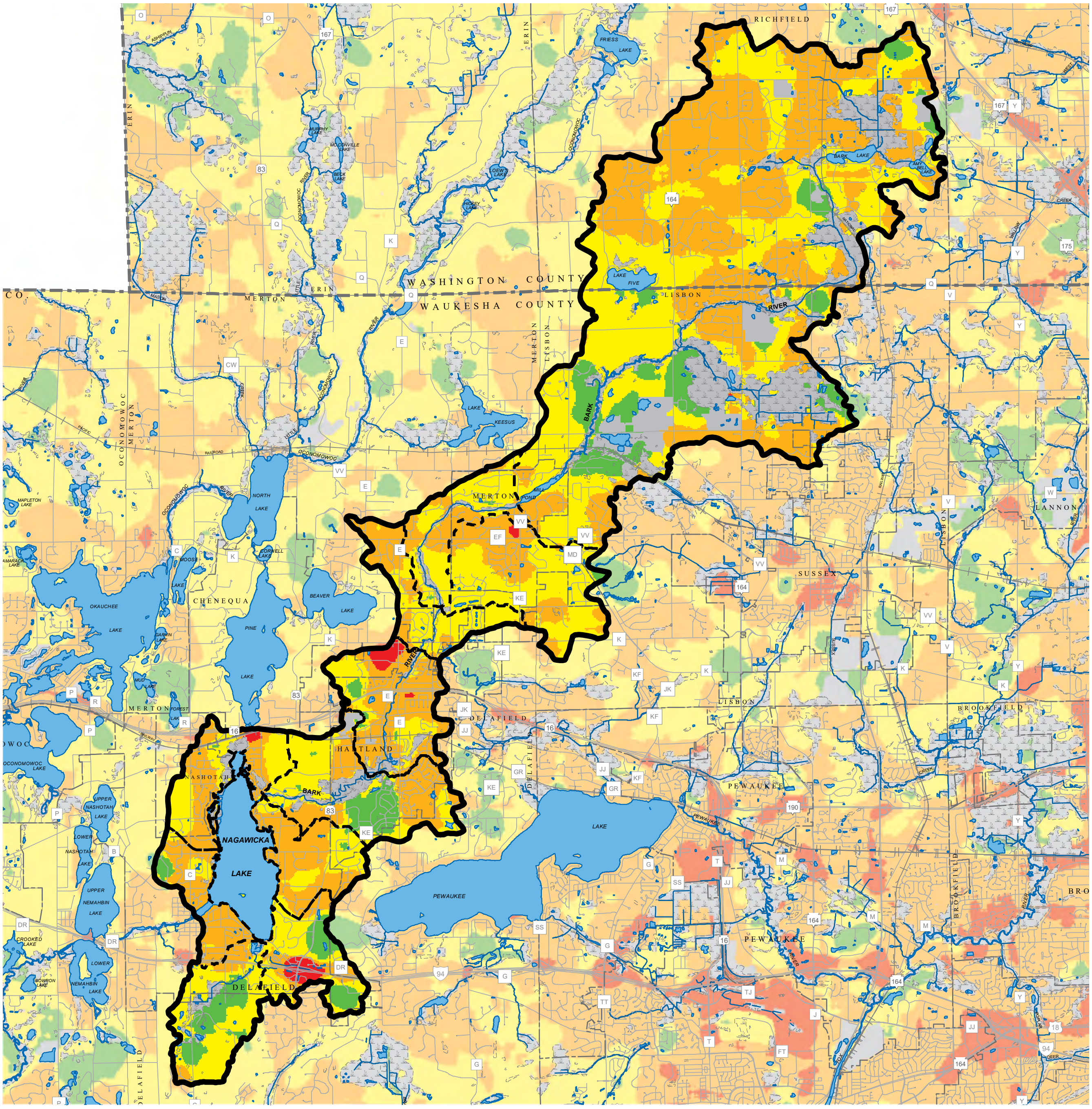
[42] *SEWRPC Planning Report No. 52,* op. cit.

[43] *Care needs to be taken to infiltrate water that does not degrade the quality of groundwater resources. More information regarding stormwater infiltration is available from many sources, including the following website: stormwater.pca.state.mn.us/index.php?title=Main_Page.*

Map 2.13
Nagawicka Lake Watershed Groundwater Recharge Potential



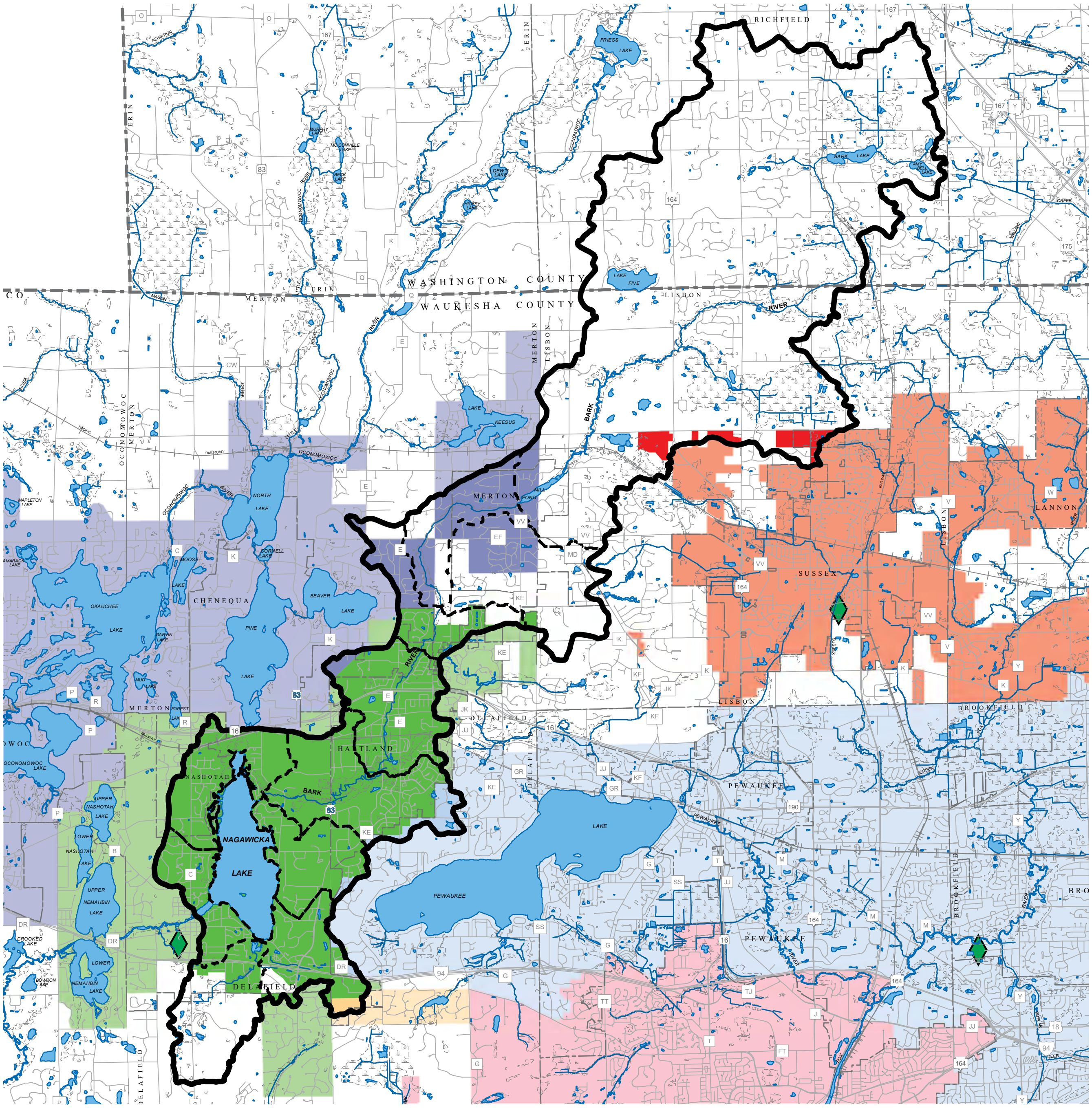
LOW		SURFACE WATER	
MODERATE		STREAM	
HIGH		WATERSHED BOUNDARY	
VERY HIGH		SUB-BASIN BOUNDARY	
UNDEFINED		WETLAND	

0 3,000 6,000 12,000 Feet

Source: SEWPRC

Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

Map 2.14
Adopted Sanitary Sewer Service Areas Within the Nagawicka Lake Watershed: 2019



CITY OF OCONOMOWOC

CITY OF WAUKESHA OR FOX RIVER WATER POLLUTION CONTROL COMMISSION

DELAFIELD-HARTLAND WATER POLLUTION CONTROL COMMISSION

FOX RIVER WATER POLLUTION CONTROL COMMISSION

VILLAGE OF SUSSEX

EXISTING TREATMENT PLANTS: DECEMBER 2010

SURFACE WATER

STREAM

WATERSHED BOUNDARY

SUB-BASIN BOUNDARY

WETLAND

N

0 3,000 6,000 12,000 Feet

Source: SEWRPC

Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

Watershed Jurisdictions, Demographics, and Land Use

Watershed Jurisdictions

As noted above the Nagawicka Lake watershed lies entirely within Washington and Waukesha Counties (see Map 2.1). The largest portion of the watershed is in the Village of Richfield with 31 percent, followed by the Town of Lisbon with 25 percent, and the City of Delafield with 16 percent. The remaining 28 percent of the watershed (in descending order) is comprised by the Village of Hartland, Village of Merton, Town of Merton, Town of Delafield, Village of Nashotah, Village of Chenequa, and Village of Sussex.

Jurisdictional Roles and Responsibilities

Natural resources are protected to some extent under Federal, State, and local law. The Clean Water Act regulates surface water quality at the national level. In Wisconsin, the WDNR has the authority to administer the provisions of the Clean Water Act. The USEPA, U.S. Army Corps of Engineers, Natural Resources Conservation Service, and the U.S. Fish and Wildlife Service work with the WDNR to protect natural areas, wetlands, and threatened and endangered species. The Federal Safe Drinking Water Act also protects surface and groundwater resources.

Counties and other local governments in the watershed have ordinances regulating land development and protecting surface waters. Comprehensive zoning ordinances represent some of the most important and significant tools available to local units of government in directing the proper use of lands within their jurisdictions. Local zoning regulations include general, or comprehensive, zoning regulations and special-purpose regulations governing floodplain and shoreland areas. General zoning and special-purpose zoning regulations may be adopted as a single ordinance or as separate ordinances; they may or may not be contained in the same document. Any analysis of locally proposed land uses must take into consideration the provisions of both general and special-purpose zoning. The ordinances administered by the units of government within the watershed are summarized in Table 2.8. In addition, since State laws governing County and local zoning regulations are often revised, Commission staff provides periodic summaries of the most up-to-date changes that can be read and downloaded at: www.sewrpc.org/SEWRPCFiles/CommunityAssistance/Smartgrowth/fact_sheet_implementation_of_comp_plans.pdf.

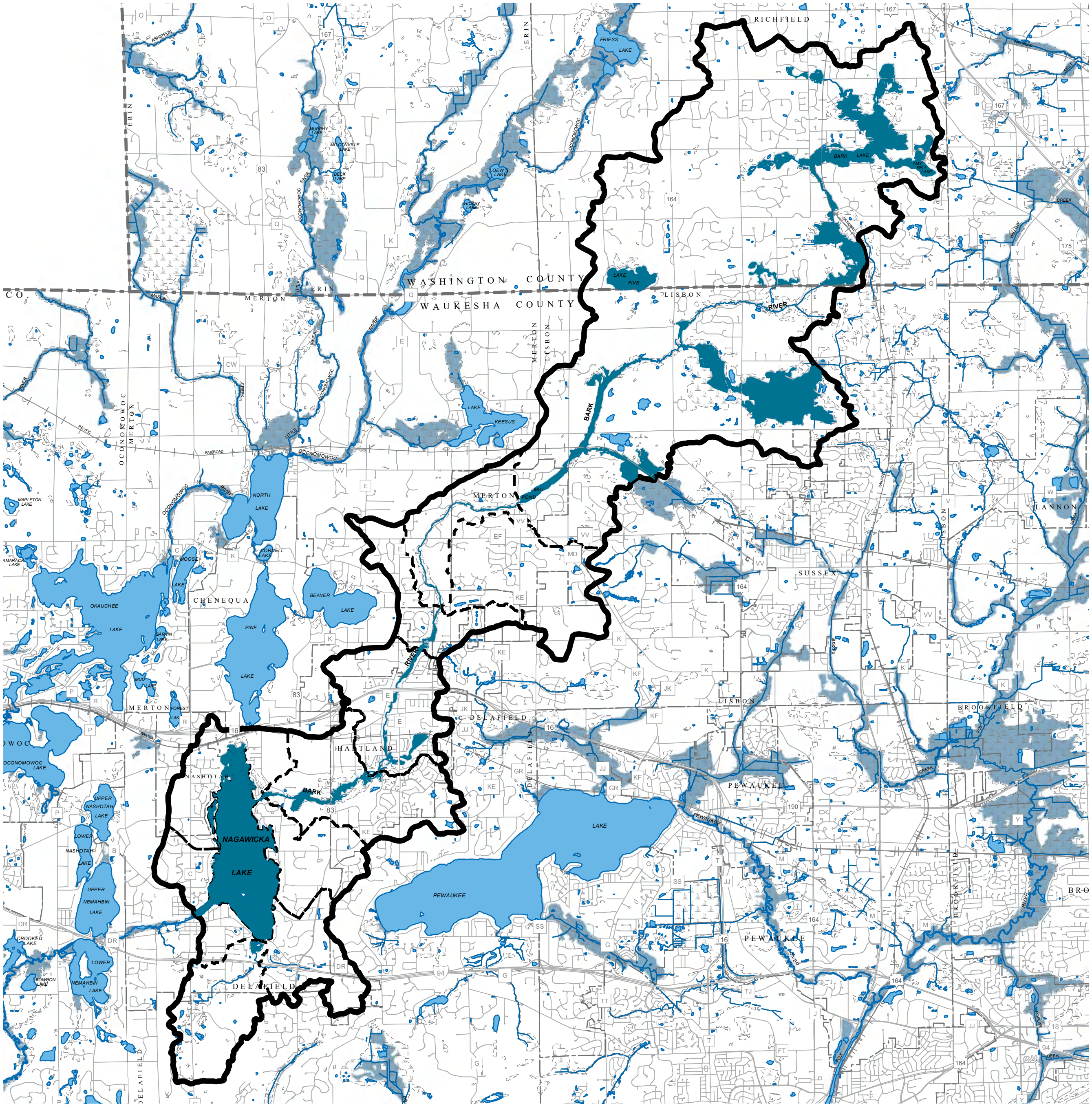
Other governmental entities with watershed jurisdictional or technical advisory roles include: the Wisconsin Department of Agriculture, Trade, and Consumer Protection; the University of Wisconsin-Extension; Washington County Planning and Parks Department; and Waukesha County Department of Parks and Land Use.

<u>Floodland Zoning</u>

Section 87.30 of the *Wisconsin Statutes* requires that counties, with respect to their unincorporated areas; cities; and villages adopt floodplain zoning to preserve the floodwater conveyance and storage capacity of floodplain areas and to prevent the location of new flood-damage-prone development in flood hazard areas. The minimum standards that such ordinances must meet are set forth in Chapter NR 116, "Wisconsin's Floodplain Management Program," of the *Wisconsin Administrative Code*. The required regulations govern filling and development within a regulatory floodplain, which is defined as the area that has a 1 percent annual probability of being inundated. The 1-percent-annual-probability (100-year recurrence interval) floodplains within the Nagawicka Lake watershed are shown on Map 2.15. As required under Chapter NR 116, local floodland zoning regulations must prohibit nearly all forms of development within the floodway, which is that portion of the floodplain required to convey the 1-percent-annual-probability peak flood flow. Local regulations must also restrict filling and development within the flood fringe, which is that portion of the floodplain located outside the floodway that would be covered by floodwater during the one-percent-annual-probability flood. Allowing the filling and development of the flood fringe area reduces the floodwater storage capacity of the natural floodplain, and may, thereby, increase downstream flood flows and stages. There are approximately 3,225 acres of floodplains within the Nagawicka Lake watershed as shown on Map 2.15.

The Washington and Waukesha County ordinances related to floodplain zoning recognize existing uses and structures and regulate them in accordance with sound floodplain management practices. These ordinances are intended to: 1) regulate and diminish the proliferation of nonconforming structures and uses in floodplain areas; 2) regulate reconstruction, remodeling, conversion and repair of such nonconforming structures—with the overall intent of lessening the public responsibilities attendant to the continued and

Map 2.15
Floodplains Within the Nagawicka Lake Watershed



1 PERCENT ANNUAL PROBABILITY (100-YEAR RECURRENCE INTERVAL) FLOODPLAIN

SURFACE WATER

STREAM

WATERSHED BOUNDARY

SUB-BASIN BOUNDARY

WETLAND

0 3,000 6,000 12,000 Feet

Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

Source: FEMA and SEWPRC

expanded development of land and structures inherently incompatible with natural floodplains; and 3) lessen the potential danger to life, safety, health, and welfare of persons whose lands are subject to the hazards of floods. Floodplain zoning is in place for each of the towns in Washington and Waukesha Counties (see Table 2.8).

Population and Households

Data on population and numbers of households in the Nagawicka Lake watershed from 1960 to 2010 are shown in Table 2.9. Over that time period, the resident population grew from about 7,850 to 30,330 individuals and the number of households grew from about 1,960 to 11,130. The greatest increase in both population and the number of households occurred between 1970 and 1980, however, there has been a steady growth in both population and households since 1990, as shown in Table 2.9. Based upon the adopted regional land use plan, the population and number of resident households in the Nagawicka Lake watershed are projected to continue to increase, which is consistent with planned increases in urban land uses as shown in Table 2.10.[44]

Historical Urban Growth

Historical urban growth within the Nagawicka Lake watershed is summarized on Map 2.16 and Table 2.10. Much of the early growth (pre-1950s) in the lower parts of the watershed was focused along the shoreline of Nagawicka Lake and within the Village of Hartland and along the shorelines of Lake Five, Bark Lake, and Amy Belle Lake in the upstream portions of the watershed. Between 1950 and 1970, the majority of growth continued to occur around Nagawicka Lake and in the Village of Hartland in the lower portions of the watershed. From 1970 to 2010, growth has continued to occur throughout the entire watershed. Hence, urban runoff is an important issue in this watershed, and measures to mitigate that impact are considered in later sections of this report.

Land Use

Existing year 2010 land use data and planned land use projections for the watershed were developed by Commission staff.[45,46] Urban land uses comprise about 43 percent of the watershed area under 2010 land use conditions (Map 2.17 and Table 2.11). The majority of the commercial and industrial urban development is in the lower portions of the watershed. Residential lands, which comprise the greatest amount of urban development (about 28 percent), are widely distributed throughout the watershed. Agricultural land uses accounted for about 23 percent of the watershed area in 2010 and the majority of those lands are located in the upper portions of the watershed. Wetlands comprise nearly 11 percent and woodlands also cover about 11 percent of the watershed. Surface water covers 1.3 percent.

Under planned land use conditions (see Table 2.11 and Map 2.18), agricultural land is expected to be reduced by nearly 44 percent, or 3,635 acres. Urban development is planned to increase by about 137 percent, comprising 59 percent of the watershed as shown in Table 2.11.

Comparison of the existing versus planned land use as shown in Map 2.19 indicates the agricultural land, open land, and woodland that would be expected to be converted to urban uses under planned conditions. Hence, agricultural land will cover a smaller portion of the watershed and will no longer be dominant in the upper portion of the watershed as shown in Table 2.11. Based upon this planned land use condition, urban runoff is anticipated to have much more influence in the watershed than agricultural lands in the future (see "Simulated Phosphorus and Sediment Loads" in Section 2.2, "Water Quality").

When urban development in a watershed increases, the amount of impervious surface area increases. Many researchers throughout the United States, including researchers at the WDNR, report that the amount

[44] *SEWRPC Planning Report No. 55,* VISION 2050: A Regional Land Use and Transportation Plan for Southeastern Wisconsin, *July 2017.*

[45] *Ibid.*

[46] *The existing land use data for this study area is based upon 12-inch pixel color year 2010 orthophotography and cadastral mapping. SEWRPC has over 60 land cover classifications and a spatial resolution scale of 1-inch equals 200 feet, which is equivalent to the National Map Accuracy Standards (NMAS) of 90 percent of the positions of well-defined points as determined from the orthophotographs to be within 6.6 feet of their correct position as determined by field measurement.*

Table 2.8
Land Use Regulations in the Nagawicka Lake Watershed: 2019

	Type of Ordinance					
Unit of Government	General Zoning	Floodplain Zoning	Shoreland or Shoreland-Wetland Zoning	Subdivision Control	Erosion Control and Stormwater Management	Groundwater Protection
Waukesha County	Adopted	Adopted	Adopted and WDNR approved	Floodplain and shoreland only	Adopted	--
City of Delafield	Adopted	Adopted	Adopted	Adopted	Adopted	--
Village of Chenequa	Adopted	None[a]	Adopted	Adopted[b]	Adopted[c]	--
Village of Hartland	Adopted	Adopted	Adopted	Adopted	Adopted	--
Village of Merton	Adopted	Adopted	Adopted	Adopted	Adopted	--
Village of Nashotah	Adopted	Adopted	Adopted	Adopted	Adopted	--
Town of Delafield	Adopted	County ordinance	County ordinance	Adopted	County ordinance	--
Town of Lisbon	Adopted	County ordinance	County ordinance	Adopted	County ordinance	--
Town of Merton	Adopted	County ordinance	County ordinance	Adopted	County ordinance	--
Washington County	--[d]	Adopted[d]	Adopted and WDNR approved[d]	Adopted	Adopted	--
Village of Richfield	Adopted	Adopted	Adopted	Adopted	Adopted	Adopted

[a] *Floodplains have been identified or mapped for certain areas.*

[b] *Adopted as part of the zoning code.*

[c] *Erosion control ordinance only.*

[d] *Washington County rescinded its general zoning ordinance in 1986. All towns in the County have adopted a town zoning ordinance. County floodplain and shoreland regulations continue to apply in unincorporated (town) areas.*

Source: SEWRPC

Table 2.9
Populations and Households in the Nagawicka Lake Watershed: 1960 – Planned

Year	Population	Change from Previous Decade		Households	Change from Previous Decade	
		Number	Percent		Number	Percent
1960	7,846	--	--	1,958	--	--
1970	10,964	3,118	40	2,996	1,038	53
1980	17,958	6,994	64	5,448	2,452	82
1990	20,914	2,956	16	6,874	1,426	26
2000	26,068	5,154	25	9,210	2,336	34
2010	30,332	4,264	16	11,132	1,922	20
Planned	36,411	6,079	20	14,070	2,938	26

Source: U.S. Census Bureau and SEWRPC

Table 2.10
Historical Urban Land Use Increase in the Nagawicka Lake Watershed

Land Use Categories[a]	2010		Planned		Change 2010 – Planned	
	Acres	Percent of Total Tributary Drainage Area	Acres	Percent of Total Tributary Drainage Area	Acres	Percent
Urban						
Residential						
Single-Family, Suburban Density	2,169	7.6	3,837	13.4	1,668	176.9
Single-Family, Low Density	5,137	17.9	6,397	22.3	1,260	124.5
Single-Family, Medium Density	561	2.0	583	2.0	22	103.9
Single-Family, High Density	0	0.0	0	0.0	0	
Multi-Family	208	0.7	329	1.1	121	158.2
Commercial	378	1.3	548	1.9	170	145.0
Industrial	220	0.8	397	1.4	177	180.5
Governmental and Institutional	477	1.7	746	2.6	269	156.4
Transportation, Communication, and Utilities	2,471	8.6	3,224	11.3	753	130.5
Recreational	777	2.7	874	3.0	97	112.5
Subtotal	12,398	43.3	16,935	59.0	4,537	136.6
Rural					0	
Agricultural	6,483	22.6	2,848	9.9	-3,635	-43.9
Other Open Lands	2,425	8.5	1,464	5.2	-961	-60.4
Wetlands	3,027	10.6	3,027	10.6	0	100.0
Woodlands	3,045	10.6	3,025	10.6	-20	-99.3
Water	381[b]	1.3	411	1.4		
Extractive	902	3.1	951	3.3	49	105.4
Landfill	--	--	--	--		
Subtotal	16,263	56.7	11,726	41.0	-4,537	-72.1
Total	28,661[c]	100.0	28,661[c]	100.0	0	--

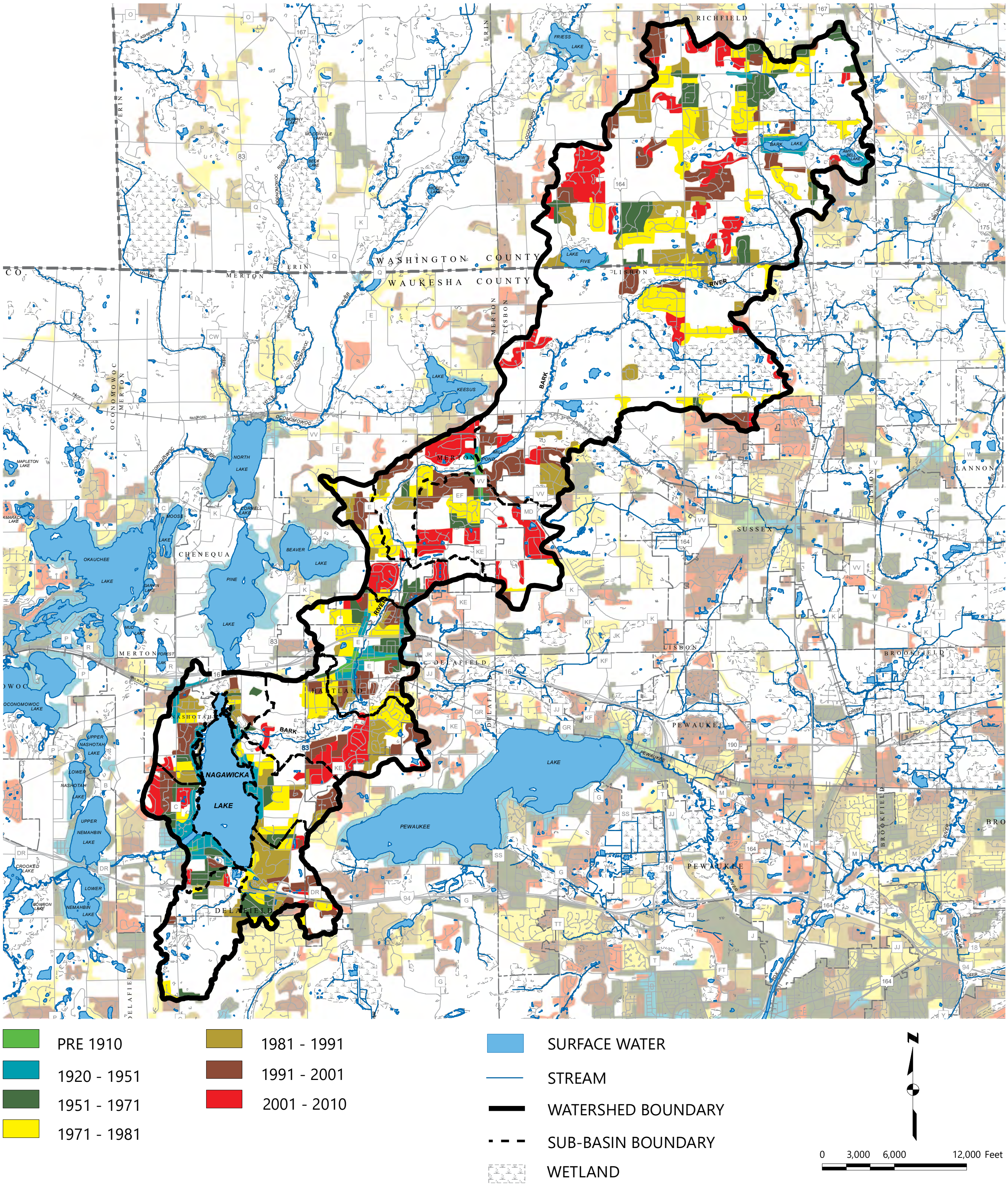
[a] *Parking included in associated use.*

[b] *Acres of open water exist within the upland area draining to Nagawicka Lake; Nagawicka Lake occupies an additional 1,010 acres.*

[c] *The current measurement for the watershed draining to Nagawicka Lake is 29,666 acres; the 5 acre discrepancy between that value and the combined total for Nagawicka Lake (1,010 acres) with the total listed in this table (28,661 acres) can be attributed to rounding, to the nearest whole acre, the individual acre measurements in the table.*

Source: SEWRPC

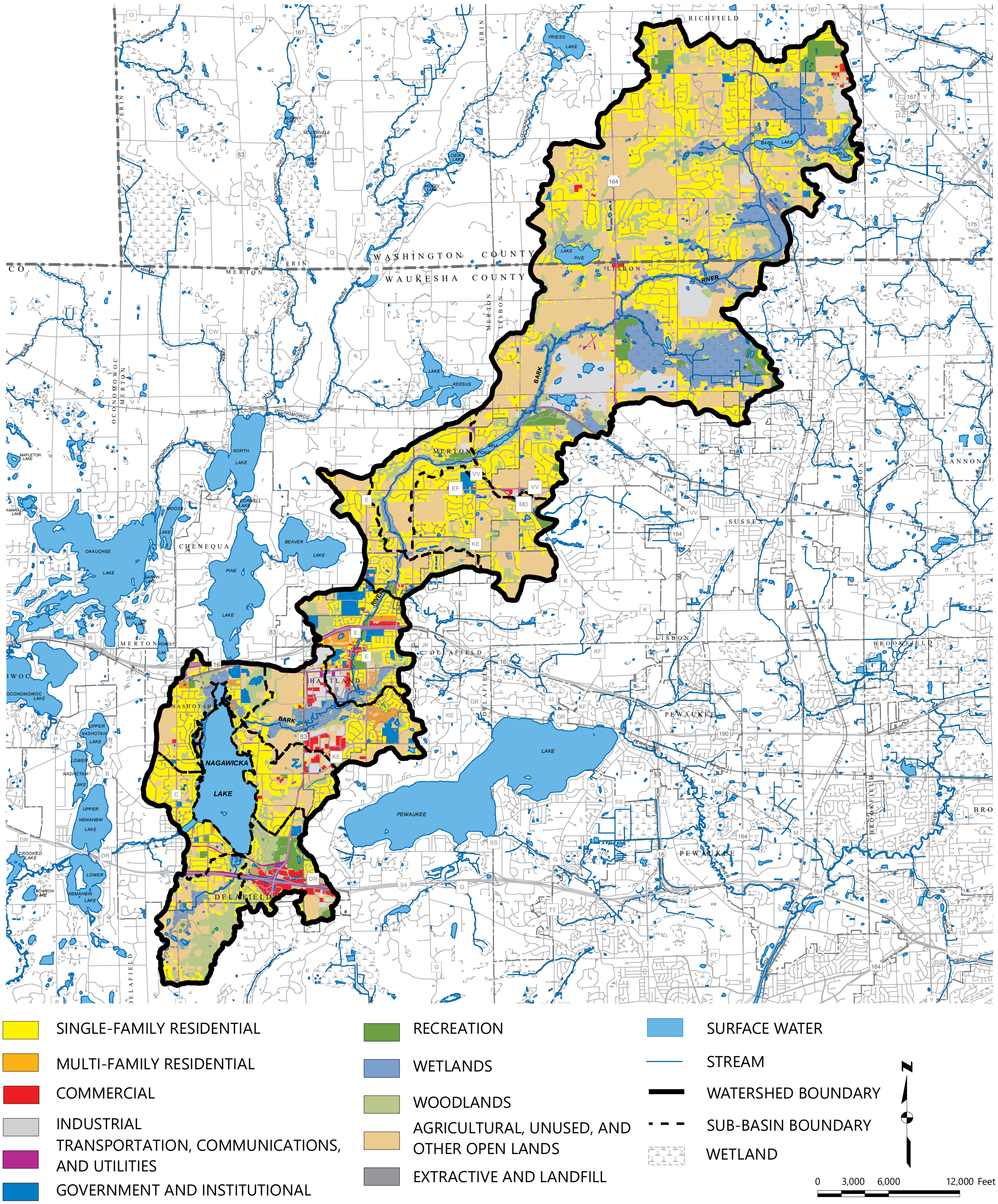
Map 2.16
Historical Urban Growth Within the Nagawicka Lake Watershed: 1850 – 2010



Source: SEWPRC

Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

Map 2.17
Nagawicka Lake Watershed 2010 Land Use



Source: SEWPRC

of *connected* impervious surface is the best indicator of the level of urbanization in a watershed.[47] Directly connected impervious area is area that discharges directly to the stormwater drainage system, and, ultimately, to a stream without the potential for infiltration through discharge to pervious surfaces or facilities specifically designed to infiltrate runoff. In the absence of mitigating controls on runoff, impervious surfaces:[48]

- Contribute to the hydrologic changes that degrade waterways
- Are a major component of the intensive land uses that generate pollution
- Prevent natural pollutant attenuation or removal in the soil by preventing infiltration
- Serve as an efficient conveyance system transporting pollutants into waterways

Table 2.11
Existing and Planned Land Use Within the Nagawicka Lake Watershed: 2010 Versus Planned

Year	Land Converted to Urban Use During Time Period (acres)	Total Urban Use (acres)	Total Urban Land Use as a Percentage of Watershed Area (percent)
Before 1850	0	0	0.0
1850-1880	66	66	0.2
1881-1920	133	198	0.7
1921-1950	609	808	2.7
1951-1963	445	1,253	4.2
1964-1970	953	2,206	7.4
1971-1975	1,129	3,335	11.2
1976-1980	1,821	5,157	17.4
1981-1985	977	6,133	20.7
1986-1990	766	6,899	23.3
1991-1995	1,167	8,067	27.2
1996-2000	1,122	9,189	31.0
2001-2010	2,352	11,541	38.9

Source: SEWRPC

Research over the last 20 years shows a strong relationship between the imperviousness of a drainage basin and the health of receiving streams.[49] Studies have found that relatively low levels of urbanization—8 to 12 percent connected impervious surface—can cause subtle changes in physical (increased temperature and turbidity) and chemical (reduced dissolved oxygen and increased pollutant levels) properties of a stream, leading to a decline in the biological integrity of the stream. For example, each 1 percent increase in watershed imperviousness can lead to an increase in water temperature of nearly 2.5°F.[50] While this temperature increase may appear to be small in magnitude, this small increase can have significant impacts on fish, such as trout and other biological communities that have a low tolerance to temperature fluctuations or require specific thermal ranges.

The Nagawicka Lake watershed's overall proportion of urban land use in 2010 likely corresponds to a level of connected imperviousness that exceeds the threshold level of 6 to 11 percent at which negative biological impacts can be expected to occur. In addition, the estimated levels of imperviousness by sub-basin for year 2010 and planned land use, as shown in Figure 2.12, are also expected to exceed the 6 to 11 percent range, except for sub-basin 9. This indicates that, in the absence of mitigating measures, these moderate to high levels of urban development would be expected to contribute to the degradation of

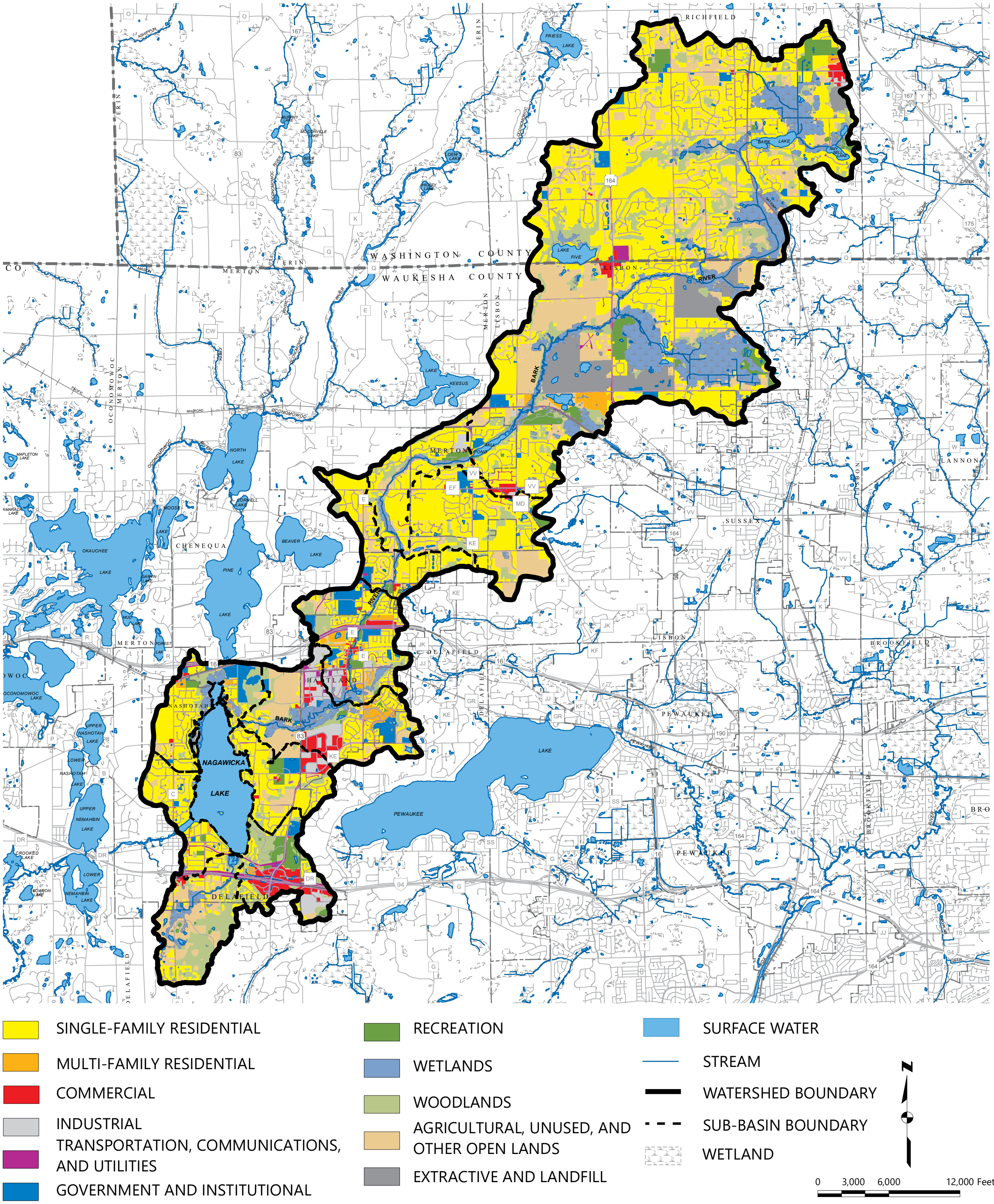
[47] *L. Wang, J. Lyons, P. Kanehl, and R. Bannerman, "Impacts of Urbanization on Stream Habitat and Fish across Multiple Spatial Scales,"* Environmental Management*, Vol. 28, 2001, pp. 255-266.*

[48] *Dane County Regional Planning Commission,* Dane County Waterbody Classification Study-Phase I*, March 2007.*

[49] *L. Wang, J. Lyons, P. Kanehl, R. Bannerman, and E. Emmons, "Watershed Urbanization and Changes in Fish Communities in Southeastern Wisconsin Streams,"* Journal of the American Water Resources Association *36(5):1173-1189, 2000; L. Wang, J. Lyons, P. Kanehl, and R. Gatti, "Influences of Watershed Land Use on Habitat Quality and Biotic Integrity in Wisconsin Stream,"* Fisheries *22(6):6-12, 1997; C. Arnold and C.J. Gibbons, "Impervious Surface Coverage: The Emergence of a Key Environmental Indicator,"* Journal of the American Planning Association *62(2):243-258, 1996; T. Schueler,* Site Planning for Urban Stream Protection, *Center for Watershed Protection, 1995; M.D. Ellicot, J.P. Masterson, and R.T. Bannerman, "Impacts of Stormwater Runoff on Urban Streams in Milwaukee, Wisconsin" In* National Symposium on Water Quality, American Water Resources Association*, Middelburg, VA, 1994; and, T. Schueler,* The Importance of Imperviousness. Watershed Protection Techniques *1:100-111, 1994.*

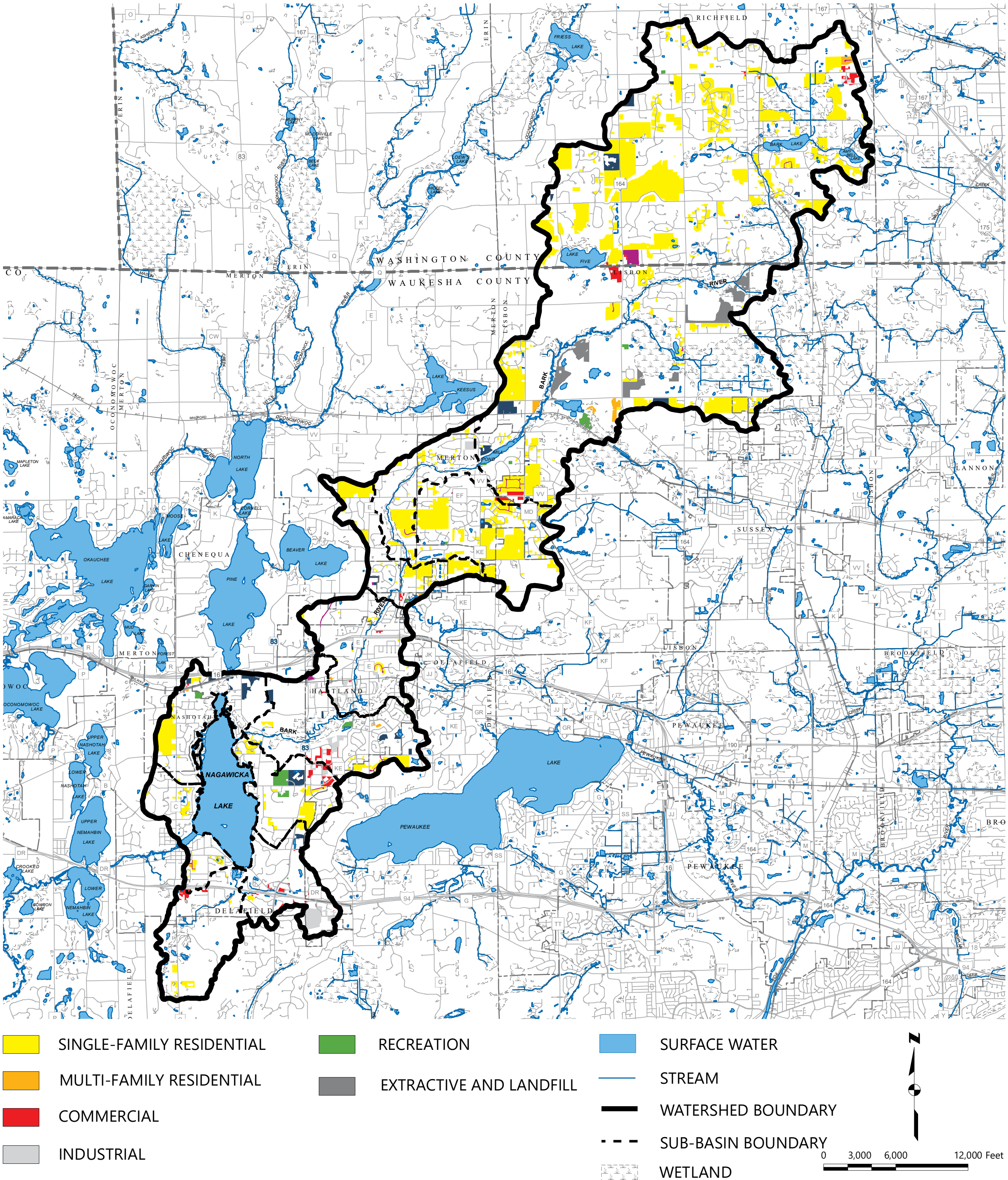
[50] *L. Wang, J. Lyons, and P. Kanehl, "Impacts of Urban Land Cover on Trout Streams in Wisconsin and Minnesota,"* Transactions of the American Fisheries Society *132: 825-839, 2003.*

Map 2.18
Nagawicka Lake Watershed Planned Land Use



Source: SEWPRC

Map 2.19
Agricultural and Open Lands Anticipated to be Coverted to Urban Land Use Between Current and Planned Conditions



Source: SEWPRC

aquatic resources, such as has been observed in other streams within southeastern Wisconsin.[51] Hence, local stormwater management practices affecting runoff volume and quality such as promoting infiltration, green infrastructure projects, and preservation of riparian buffers will be key to mitigating the consequences of development within this watershed. In addition, agricultural land management practices will also remain an important component to reduce pollutant loads to Nagawicka Lake, particularly during stormwater events.

Natural Resource Elements

Many important interlocking and interacting relationships occur between living organisms and their environment. The destruction or deterioration of any one element may lead to a chain reaction of deterioration and destruction among the others. The drainage of wetlands, for example, may have far-reaching effects. Such drainage may destroy fish spawning grounds, wildlife habitat, groundwater recharge areas, and natural filtration and floodwater storage areas. The resulting deterioration of surface water quality may, in turn, lead to a deterioration of the quality of the groundwater. Groundwater serves as a source of domestic, municipal, and industrial water supply and provides low flows in rivers and streams. The destruction of woodlands and other upland cover types, which may have taken a century or more to develop, may result in soil erosion and stream siltation and in more rapid runoff and increased flooding, as well as destruction of wildlife habitat. Although the effects of any one of these environmental changes in isolation may not be overwhelming, the combined effects may lead eventually to the deterioration of the underlying and supporting natural resource base, and of the overall quality of the environment for life. The need to protect and preserve the environmental corridors and their associated complexes of wetland, upland, and critical species habitats within the watershed, thus, becomes apparent.

Primary Environmental Corridors

Primary environmental corridors (PEC) include a wide variety of important resource and resource-related elements. By definition, they are at least 400 acres in size, two miles in length, and 200 feet in width.[52] There are two separate PECs in the watershed under existing conditions, one in the upper portion of the watershed and one in the lower portion of the watershed that includes Nagawicka Lake, which together encompass about 6,633 acres, or about 22 percent, of the Nagawicka Lake watershed. This PEC represents a composite of the best remaining elements of the natural resource base in the watershed, and contains almost all of the best remaining uplands, wetlands, and wildlife habitat areas (see "Natural Areas and Critical Species Habitat Sites" subsection). It is also important to note that these high-quality corridors are a part of one much larger contiguous PEC that is shared with the neighboring lakes located west, north, and east of Nagawicka Lake as shown on Map 2.20. Hence, Nagawicka Lake and its associated shorelands are part of the highest quality natural resources within the watershed as well as the neighboring watersheds. This is why management of those areas is vital to protecting and maintaining the quality and integrity of this resource.[53]

Secondary Environmental Corridors

Secondary environmental corridors (SEC) are at least 100 acres in size and one mile long. In 2010, as shown on Map 2.20, there were three large designated secondary environmental corridors within the Nagawicka Lake watershed that together encompass about 280 acres, or less than one percent, of the Nagawicka Lake watershed. Although these areas are small compared to the PEC, they provide vital connections between PEC and Isolated Natural Resource Areas.

Isolated Natural Resource Areas

Smaller concentrations of natural resource features that have been separated physically from environmental corridors by intensive agricultural or urban land uses have also been identified. These natural resource areas, which are at least five acres in size, are referred to as isolated natural resource areas (INRA) and are shown on Map 2.20. Widely scattered throughout the watershed, isolated natural resource areas covered about 593 acres, or nearly 2 percent, of the total study area in 2010. These INRAs still contains a variety of

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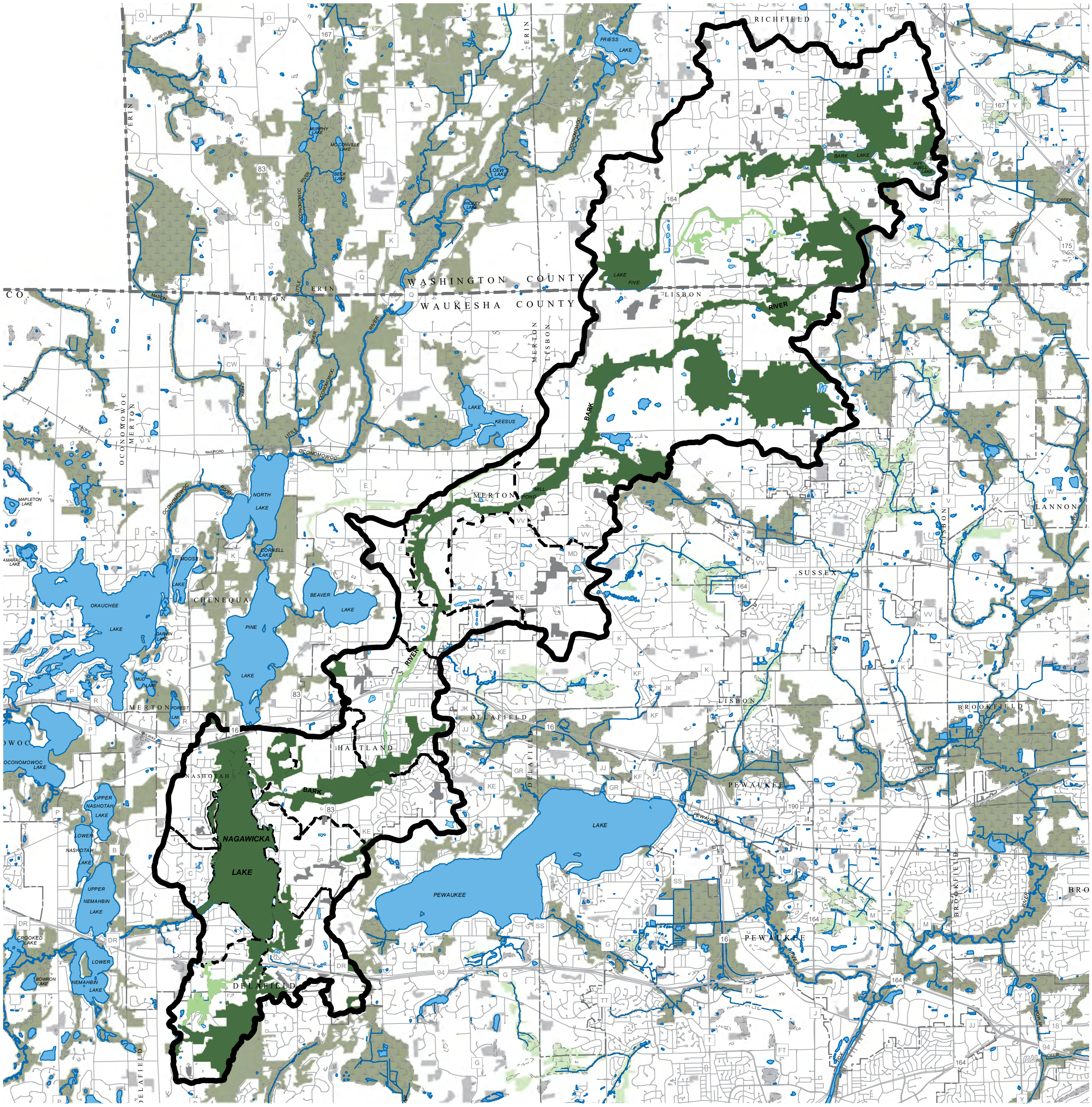
[51] *SEWRPC Technical Report No. 39,* Water Quality Conditions and Sources of Pollution in the Greater Milwaukee Watersheds*, November 2007.*

[52] *SEWRPC Planning Report No. 42,* A Regional Natural Areas and Critical Species Habitat Protection and Management Plan for Southeastern Wisconsin, Amendment*, December 2010.*

[53] *For more information, see www.sewrpc.org/SEWRPCFiles/Publications/ppr/rbmg-001-managing-the-waters-edge.pdf.*

Map 2.20
Environmental Corridors and Isolated Natural Features Within the Nagawicka Lake Watershed



PRIMARY ENVIRONMENTAL CORRIDOR

SECONDARY ENVIRONMENTAL CORRIDOR

ISOLATED NATURAL RESOURCE AREA

SURFACE WATER

STREAM

WATERSHED BOUNDARY

SUB-BASIN BOUNDARY

WETLAND

N

0 3,000 6,000 12,000 Feet

Source: SEWRPC

Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

resource functions that include facilitating surface water drainage, maintaining pockets of natural resource features, and if connected with other INRAs, SEC, or PEC potentially enhancing the movement of wildlife and dispersal of seeds for a variety of plant species.

Natural Areas and Critical Species Habitat Sites

Natural areas, as defined by the Wisconsin Natural Areas Preservation Council, are tracts of land or water so little modified by human activity, or sufficiently recovered from the effects of such activity, that they contain intact native plant and animal communities believed to be representative of the pre-European settlement landscape (see Map 2.21). Natural areas are generally comprised of wetland or upland vegetation communities and/or complex combinations of both these fundamental ecosystem units. In fact, some of the highest quality natural areas within the Southeastern Wisconsin Region, as well as in the Nagawicka Lake watershed, are wetland complexes that have maintained adequate or undisturbed linkages (i.e., landscape connectivity) between the upland-wetland habitats, which is consistent with research findings in other areas of the Midwest.[54] The extent and distribution of wetland and upland areas and their relationship to the designated natural areas and critical species habitats are shown on Map 2.21.

Natural areas have been identified for the seven-county Southeastern Wisconsin Region in SEWRPC Planning Report No. 42, "*A Regional Natural Areas and Critical Species Habitat Protection and Management Plan for Southeastern Wisconsin*," published in September 1997, and amended in 2010. This plan was developed to assist Federal, State, and local units and agencies of government, and nongovernmental organizations, in making environmentally sound land use decisions including acquisition of priority properties, management of public lands, and location of development in appropriate localities that will protect and preserve the natural resource base of the Region. Washington and Waukesha Counties use this document to guide land use decisions.

The identified natural areas were classified into the following three categories:

1. Natural area of statewide or greater significance (NA-1)
2. Natural area of countywide or regional significance (NA-2)
3. Natural area of local significance (NA-3)

Classification of an area into one of these three categories was based upon consideration of several factors, including the diversity of plant and animal species and community types present; the structure and integrity of the native plant or animal community; the extent of disturbance by human activity, such as logging, grazing, water level changes, and pollution; the frequency of occurrence within the Region of the plant and animal communities present; the occurrence of unique natural features within the area; the size of the area; and the educational value.

The Nagawicka Lake watershed contains 10 natural areas of local significance (NA-3), two natural areas of countywide or regional significance (NA-2), and two critical species habitat sites as shown on Map 2.21.[55] These sites combined encompass approximately 1,031 acres, or 3.5 percent, of the total study area in 2015. These sites are distributed throughout the Nagawicka Lake watershed and are comprised of upland and wetland habitats that includes a variety of deep marsh, shallow marsh, and sedge meadow plant communities. These are the highest quality plant and animal communities known to exist in the watershed and can serve as a potential seed sources for restoration in other areas.

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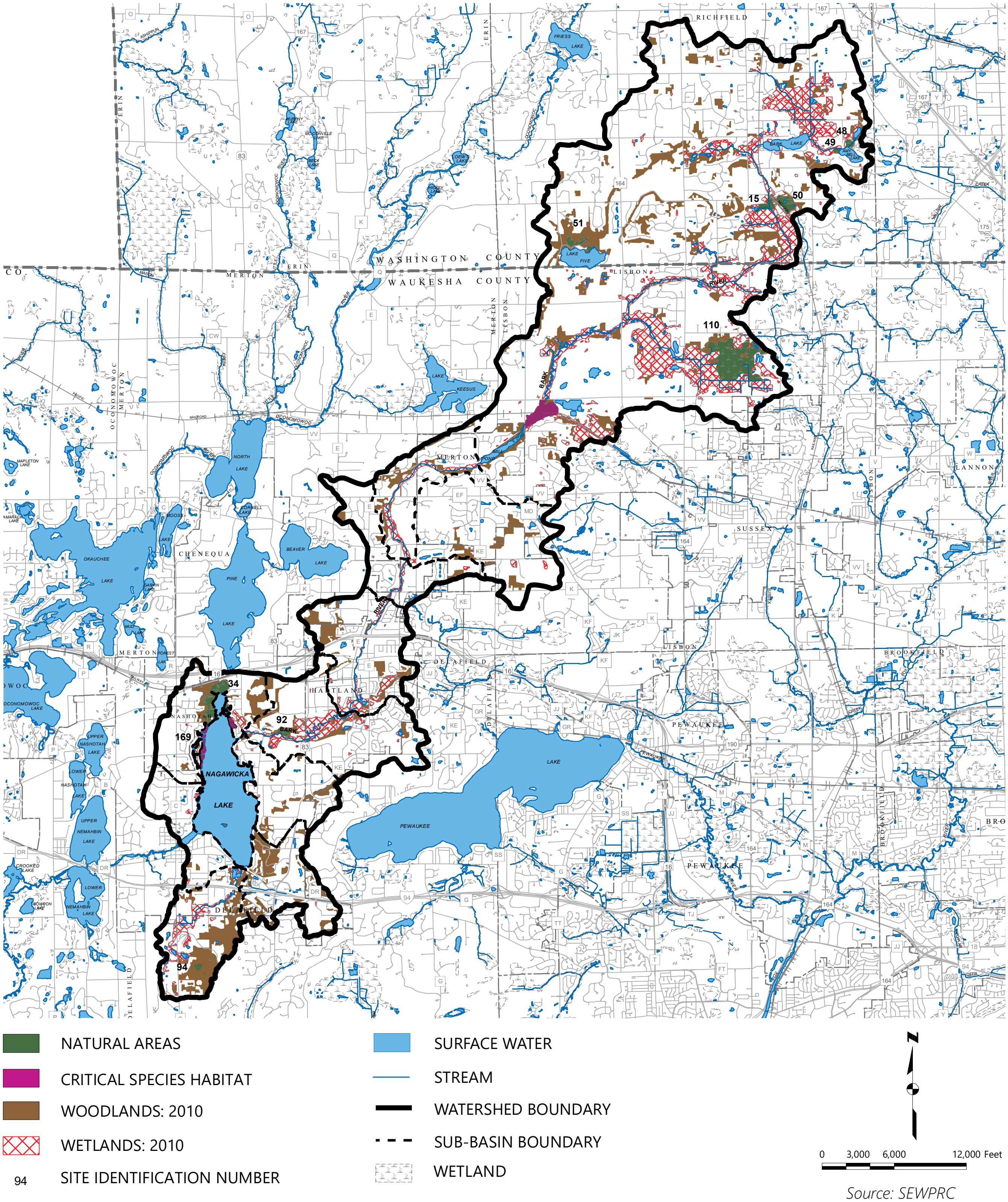
[54] *O. Attum, Y.M. Lee, J.H. Roe, and B.A. Kingsbury, "Wetland complexes and upland-wetland linkages: landscape effects on the distribution of rare and common wetland reptiles,"* Journal of Zoology *275: 245-251, 2008.*

[55] *Site numbers correspond to those presented in the Regional Natural Areas Plan (SEWRPC Planning Report No. 42, Amendment December 2010).*

Map 2.21
Natural Areas, Critical Species Habitat, Wetlands and Woodlands Within the Nagawicka Lake Watershed



Source: SEWPRC

2.2 WATER QUALITY

Water quality samples have been collected in several of Waukesha County's major lakes for over a century. Although individual studies have examined water quality in some lakes and streams for specific purposes, water quality information is not known to have been regularly or systematically collected in Waukesha County until the advent of environmentally focused antipollution laws in the late 1960s and early 1970s. For example, volunteers and the WDNR have regularly collected relevant data since 1973, while the USGS completed a detailed study of Nagawicka Lake's in the early 2000s. [56] As part of the U. S. Geological Survey study, water quality and quantity data were collected from the Lake, the Bark River, small lake-direct tributaries, and groundwater on numerous occasions between November 2002 and October 2004. Additionally, phosphorus monitoring continued until 2006. This study uses all readily available water quality data to evaluate water quality trends over the past several decades and evaluate the relative success of and/or need for waterbody management.

Unlike many other lakes and streams in Southeastern Wisconsin, Nagawicka Lake and the rivers and streams tributary to it have not been officially listed as having impaired water quality. However, the Lake ultimately does drain to the Rock River, a waterbody that has been listed as impaired and has pollutant load reduction targets.

General Concepts

Waterbody users, the general public, and regulatory agencies are all interested in water quality for a variety of reasons. Most individuals classify water quality by visual cues such as water clarity, general appearance, and the amount of visible floating debris, aquatic plants, and algae. For example, algal blooms or cloudy water can lead an observer to conclude that lake water is "dirty". Such visual cues are examples of perceived water quality. In contrast, to accurately classify and track water quality, regulators and lake managers generally base water quality judgments based on measurements of quantifiable physical, chemical, and sometimes biological factors defined through carefully designed and executed sampling protocol. These data are often collected by local volunteers, lake managers, consultants, and regulators. Lake managers then analyze resultant data for values and trends that influence, or are indicators of, water quality. Changes in water quality over time can be a powerful tool to help make sound lake management decisions.

Nagawicka Lake residents and Lake users have expressed concern that pollutants entering the Lake from various sources may compromise Lake water quality over time. These concerns typically are related to fertilizers and pesticides leaching from shoreline properties, fertilizer and sediment washing into the lake from urban and agricultural properties, a wide variety of substances carried directly to the Lake with rainfall and snowmelt, and sediment, nutrients, and other pollutants contributed to the lake by the Bark River. Lake resident/user concern about excessive aquatic plant growth underscores the stated interest in water quality given that water quality profoundly influences the overall fertility of the Lake and its ability to support nuisance-level aquatic plant growth.

Several analyses are commonly used to quantitatively measure water quality. Common water quality indicators include water clarity, water temperature and the concentrations of nitrogen, phosphorus, chlorophyll-*a*, and dissolved oxygen (see Table 2.12 for further information regarding these parameters). These parameters may interact with one another in a variety of ways. For example, certain sources of pollution tend to increase a lake's phosphorus concentration, diminish water clarity (due to algal growth in the water column), and increase abundance of chlorophyll-*a* (a measure of algae content). In addition to these basic parameters, a number of other analyses can help lake managers quantify the "general health" of a lake. For example, the abundance of the bacteria *Escherichia coli*, commonly known as *E. coli*, is often measured to evaluate if water is safe for swimming while chloride concentrations are an indicator of the overall amount of human-derived pollution entering a lake.[57] To develop and judge the success of a plan that helps maintain and improve water quality, key water-quality indices must be regularly measured over extended periods of time.

[56] *Garn, 2006*, op. cit.

[57] *Chloride is used as an indicator of human-derived pollution because it is usually naturally present throughout the Region at low concentrations. Chloride is a "conservative pollutant" meaning that it remains in the environment once released and is not attenuated by natural processes other than dilution. High chloride concentrations may result from road deicer runoff, fertilizer application, and private onsite wastewater treatment systems that discharge to groundwater that in turn provides baseflow to streams and lakes, and a long list of other human-derived sources.*

Table 2.12
Water Quality Parameter Descriptions, Typical Values, and Regulatory Limits/Guidelines

Parameter	Description	Southeastern Wisconsin Values[a]		Regulatory Limit or Guideline	Nagawicka Lake Values	
		Median	Range		Median	Range
Chloride (mg/L)	Low concentrations (e.g., < 5 mg/L) naturally occur in lakes due to natural weathering of bedrock and soils. Human activities increase concentrations (e.g., road salts, wastewater, water softener regeneration) and can effect certain plants and animals. Chloride remains in solution once in the environment and **can serve as an excellent indicator of other pollutants.**	127	56.2-223	Acute toxicity[b,c] 757 Chronic toxicity[b,d] 395	24[e]	19-74.1
Chlorophyll-*a* (µg/L)	The major photosynthetic "green" pigment in algae. The amount of chlorophyll-*a* present in the water is an indicator of the biomass, or amount of algae, in the water. **Chlorophyll-*a* levels above 10 µg/L generally result in a green coloration of the water** that may be severe enough to impair recreational activities such as swimming or water-skiing and are commonly associated with eutrophic lake conditions	9.9	1.8-706.1	2.6[f]	3.32[e]	1.17-5.79
Dissolved Oxygen (mg/L)	Dissolved oxygen levels are one of the most critical factors affecting the living organisms of a lake ecosystem. Generally, dissolved oxygen levels are higher at the surface of a lake, where there is an interchange between the water and atmosphere, stirring by wind action, and production of oxygen by plant photosynthesis. Dissolved oxygen levels are usually lowest near the bottom of a lake where decomposer organisms and chemical oxidation processes deplete oxygen during the decay process. **A concentration of 5.0 mg/L is considered the minimum level below which many oxygen-consuming organisms, such as fish, become stressed**, while many species of fish are unlikely to survive when dissolved oxygen concentrations drop below 2.0 mg/L. Oxygen concentrations above oxygen's saturation limit may also be injurious to aquatic life. Maximum theoretical oxygen saturations decrease with increasing water temperature (e.g., 146 mg/L at 32 °F and 8.0 mg/L at 80 °F.	--	--	≥5.0[g]	7.4	0-16.9
Growing Season Epilimnetic Total Phosphorus (mg/L)	Phosphorus enters a lake from natural and human-derived sources and is a fundamental building block for plant growth. Excessive phosphorus can lead to nuisance levels of plant growth, unsightly algal blooms, decreased water clarity, and oxygen depletion, all of which can stress or kill fish and other aquatic life**. A concentration of less than 0.015 mg/L is the concentration considered necessary in a two-story lake such as Nagawicka Lake** to limit algal and aquatic plant growth to levels consistent with recreational water use objectives. Phosphorus concentration exceeding 30 µg/L are considered to be indicative of eutrophic lake conditions	0.030	0.008-0.720	0.015[g]	0.013	0.006-0.065

Table continued on next page.

Table 2.12 (Continued)

Parameter	Description	Southeastern Wisconsin Values[a]		Regulatory Limit or Guideline	Nagawicka Lake Values	
		Median	Range		Median	Range
Water Clarity (feet)	Measured with a Secchi disk (a ballasted black-and-white, eight-inch-diameter plate) which is lowered into the water until a depth is reached at which the disk is no longer visible. It can be affected by physical factors, such as suspended particles or water color, and by various biologic factors, including seasonal variations in planktonic algal populations living in a lake. **Measurements less than 5 feet are considered indicative of poor water clarity and eutrophic lake conditions.**	4.6	3-12	10.9[f]	9.26	1.75-35
Water Temperature (°F)	Temperature increases above seasonal ranges are dangerous to fish and other aquatic life. Higher temperatures depress dissolved oxygen concentrations. They also serve as an indicator of increases in other pollutants.	--	--	Ambient[g] 35-77 Sub-lethal[g] 49-80 Acute[g] 77-87	46.31	32-81.5

[a] *Wisconsin Department of Natural Resources Technical Bulletin No. 138, Limnological Characteristics of Wisconsin Lakes, Richard A. Lillie and John W. Mason, 1983 except for chloride. Chloride values from a relatively limited SEWRPC Region-specific 2014 data set. Broad, Region-specific, and modern data sets will be developed as part of the ongoing SEWRPC chloride study.*

[b] *Wisconsin Administration Code Chapter NR 105, Surface Water Quality Criteria and Secondary Values for Toxic Substances. July, 2010.*

[c] *The acute toxicity criterion is the maximum daily concentration of a substance which, if not exceeded more than once every three years, ensures adequate protection of sensitive species of aquatic life and will adequately protect the designated fish and aquatic life use of the surface water.*

[d] *The chronic toxicity criterion is the maximum four-day concentration of a substance which, if not exceed more than once every three years, ensures sensitive species of aquatic life are adequately protected and will adequately protect the designated fish and aquatic life use of the surface water can be maintained.*

[e] *The median chloride concentrations likely does not reflect current conditions in the Lakes, because chloride concentrations have consistently increased over time. The most recent data better represent Lake concentrations.*

[f] *U.S. Environmental Protection Agency, Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria: Lakes and Reservoirs in Nutrient Ecoregion VII, EPA 822-B-00-009, December 2000.*

[g] *Wisconsin Administrative Code Chapter NR 102, Water Quality Standards for Wisconsin Surface Waters, November 2010.*

Source: Wisconsin Department of Natural Resources and SEWRPC

Several factors lend context to water quality analyses and should be considered when reviewing data sets. Such context can help identify past, current, and/or future water quality problems, agents that cause these problems, and the ability of the lake to maintain itself of recover. Examples of such factors are listed below.

- **Temporal and spatial water quality fluctuations.** While water quality samples are typically collected at set times and locations, they may not represent water quality everywhere in the lake at any given point in time. Furthermore, they may only reflect transient conditions occurring during a relatively brief, discrete, time period (e.g., daytime versus nighttime). To determine which water quality management efforts can help achieve goals, it is important to understand current lake conditions, contrast past values, and estimate pre-settlement and future water quality. To do this, critical parameters) are measured, simulated, and tracked over time to evaluate how water quality changes during each year and over long series of annual sampling. Water quality is also likely to vary within a lake during a given time period. For example, water quality values from various depths may differ. This data is contrasted to evaluate in-lake distribution, circulation, and physical/chemical/biological processes. Data sets suggesting deteriorating conditions can help identify pollutants and issues that should be targeted for management action.

- **Shape and hydrology.** A lake's depth, shape, water sources, circulation patterns can greatly influence a lake vulnerability to pollution and other human influence. Further, they can influence short-term and long-term water quality in all or parts of a lake. Similarly, the amount of wetland or impervious surface in a river's watershed, its channel sinuosity and slope, floodplain connectivity, and other actors influence the way streams

- **Watershed characteristics.** The types, delivery dynamics, and amounts of pollutants entering a waterbody depend upon the way runoff drains from the land surface to streams and lakes. The potential for runoff and pollutant transport is highly influenced by the type of soil, the shape of the land surface, the amount of impermeable surfaces (e.g., paved areas and rooftops), and drainage characteristics (e.g., storm sewers, floodplains, ditched streams). To illustrate, the amount of a pollutant actually reaching water bodies may be higher if slopes are steep and if the soil surface is bare, paved, drained by sewers or ditches, and/ or is relatively impermeable.

  All other conditions being the same, differing land uses can yield differing pollutants and load regimens (see Figure 2.16 for an illustrated example). For instance, agricultural land can contribute sediment (from soil eroded from cultivated areas and carried in runoff) and nutrients (from fertilizers, manure, and attached to soil particles washed off fields). The type of agricultural practices employed greatly influence the amount and timing of pollutants delivered to a lake. For example, conventional tillage can loosen soil promoting erosion while tiles and ditches may hasten runoff and reduce the ability of sediment and nutrients to be captured before they enter waterways. Conversely, conservation tillage, cover crops, and pastured lands can reduce erosion and nutrient delivery while buffer strips and novel drain tile management and discharge options can help reduce sediment and nutrient loads to waterbodies.[58] Similarly, urban land uses (e.g., residential, industrial, commercial development) can contribute sediment and nutrients and an array or other pollutants such as human-source litter and debris, pesticides, salt, heavy metals, petroleum compounds, and organic toxins component to various compounds (e.g., coal tar based pavement sealers, tire dust) while a variety of stormwater practices can help reduce runoff intensity and the mass of pollutants reaching waterbodies. Given this connection, it is important to understand past, present, and planned future land use within the watershed. Based on these land use conditions, models can estimate the amount of pollution likely entering a lake. This can help identify portions of the watershed that are more likely contributing to water quality deterioration and can therefore help focus future pollution reduction strategies and efforts.

Each of these factors is discussed in more detail in the following paragraphs.

[58] *Vegetative buffers (e.g., forests, grassed waterways, and vegetative strips) and wetlands have the natural ability to slow runoff. This encourages pollutants to be trapped, stored, and/or consumed before they enter the adjacent lake.*

Nagawicka Lake

Water quality fluctuates over short- and long-term time periods. Thorough water quality examination depends upon consistently monitoring various chemical and physical properties over extended periods of time. To allow direct data comparison over time, samples should be repeatedly collected at the same depths and locations. Such monitoring data can help evaluate the severity and nature of pollution within a waterbody, the risks associated with identified pollution, the waterbody's ability to support various fish and recreational uses, and overall waterbody health.

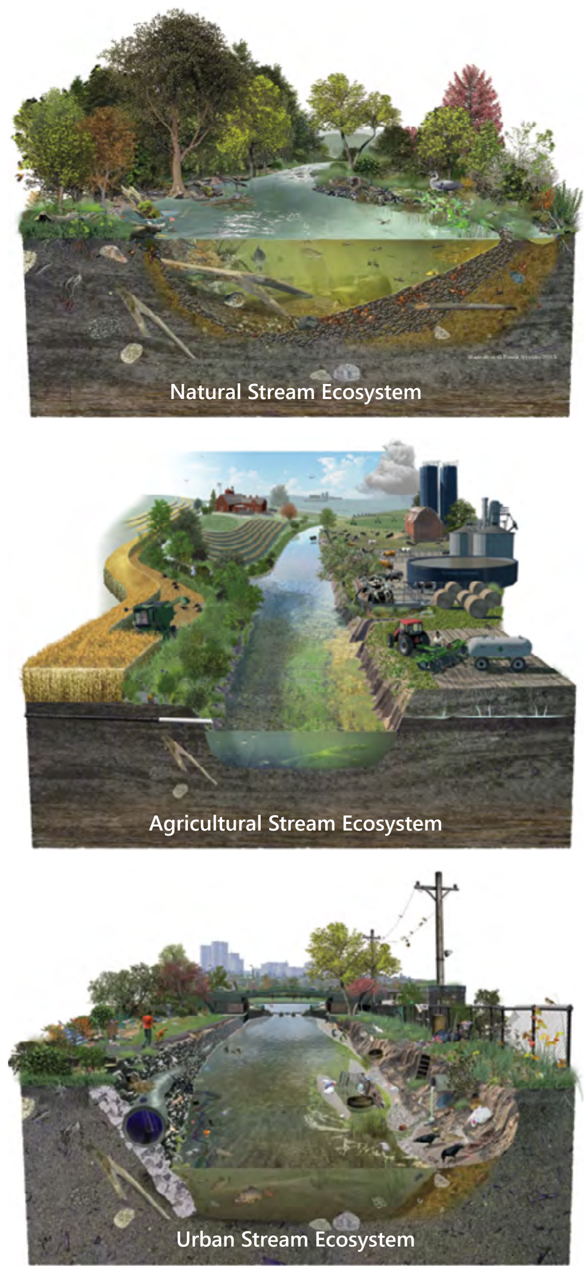
Factors Influencing Lake Water Quality

When examining lake water quality data, it is important to consider lake characteristics that provide context for evaluation. Such lake characteristics include the following examples.

- **A lake's hydraulic residence time.** Hydraulic residence time refers to the average length of time needed to replace the lake's entire water volume.[59] Hydraulic residence time helps determine how quickly pollution problems can be resolved. For example, if lake retention times are short, pollutants are flushed from a lake fairly quickly. In such cases, management efforts can likely focus on pollutant and nutrient loads contributed to the lake from the watershed. In contrast, lakes with long retention times tend to accumulate nutrients and pollutants. These can eventually become concentrated in bottom sediments. In this case, in addition to preventing external pollution, it also may be necessary to employ in-lake water quality management efforts.

- **Whether the lake stratifies and when the lake mixes.** Stratification refers to a state in which the temperature difference (and associated density difference) between the surface waters of a lake (the *epilimnion*) and the deep waters of the lake (the *hypolimnion*) is great enough to form thermal layers that impede mixing of gases and pollutants between the two layers (see Figure 2.17). If a lake stratifies, oxygen-rich surface water in contact with the atmosphere does not freely mix with water in deeper portions of the lake. Therefore, the deeper hypolimnetic water cannot exchange gases with the atmosphere. Metabolic processes continue to consume oxygen in the hypolimnion. If oxygen demands are high (such as in an enriched lake), and/or if the volume of deep isolated hypolimnetic water is small (limiting oxygen storage potential), oxygen concentrations in water in deep portions

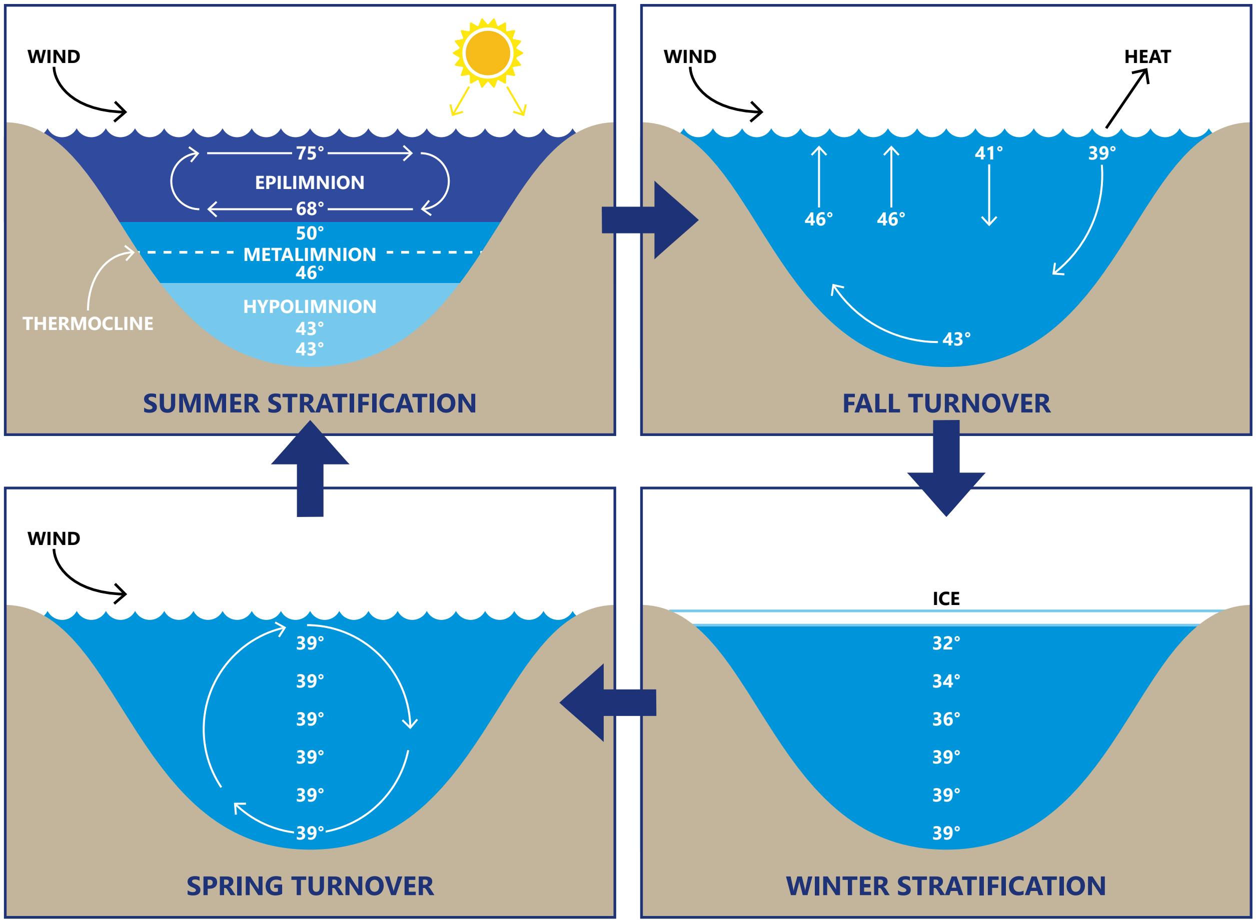
Figure 2.16
Components of Ecological Stream Health



Source: Illustration by Frank Ippolito, www.productionpost.com. Modified from Carlisle, D.M., Meador, M.R., Short, T.M., Tate, C.M., Gurtz, M.E., Bryant, W.L., Falcone, J.A., and Woodside, M.D., 2013, The Quality of our Nation's Waters—Ecological Health in the Nation's Streams, 1993–2005, *U.S. Geological Survey Circular 1391, p. 28, pubs.usgs.gov/circ/1391, and SEWRPC*

[59] *The term "flushing rate" is also commonly used to describe the amount of time runoff takes to replace one lake volume. Flushing rate is the mathematic reciprocal of hydraulic residence time. Therefore, while retention time is expressed in years and has units of time, flushing rate is typically expressed as the number of times lake water is completely replaced by runoff in one year, and is therefore a rate (units/time).*

Figure 2.17
Typical Seasonal Thermal Stratification Within Deeper Lakes



Source: Modified from B. Shaw, C. Mechenich, and L. Klessig, Understanding Lake Data, *University of Wisconsin-Extension, p. 3, 2004 and SEWRPC*

of lakes can become extremely low (hypoxic) for periods of time. Water that is completely devoid of oxygen is termed anoxic. While some lakes remain permanently stratified, stratification in most Wisconsin lakes breaks down at least twice per year (once in spring and once in fall) in response to changing seasons and ambient weather conditions.

A lake must be relatively deep to create sufficient temperature differences between surface and bottom waters for the lake to stratify. In general, lakes in Southeastern Wisconsin less than 15 feet deep are unlikely to stratify, whereas lakes with depths greater than 20 feet are likely to stratify. A lake's propensity to stratify is heavily influenced by the lake's shape, size, orientation, landscape position, surrounding vegetation, through flow, water sources, and a host of other factors. Depth to the *thermocline* (the transition layer between the epilimnion and hypolimnion, sometimes also called the *metalimnion*) can range from less than 10 feet to well over 20 feet in typical Southeastern Wisconsin lakes.

Most deep lakes in the Region stratify sometime during mid to late spring, with a short (usually less than a week) period of whole-lake water circulation and mixing (turnover) that takes place once during spring and once again in fall (see Figure 2.17). At turnover, the lake's temperature is uniform from the surface to the bottom. Lakes that stratify and turn over in the spring and fall are termed *dimictic*. Certain lakes that weakly stratify and are shaped and oriented to be exposed to wind may also mix during the summer. Lakes can also weakly stratify in winter when warmer, denser water is found in the deeper portions of the lake.

It is important to determine if lakes stratify and periodically mix. When isolated from the atmosphere, deep water may develop water quality characteristics very different than near surface water and may contain high concentrations of nutrients, little oxygen, and in some cases may have elevated concentrations of sediment and other pollutants. These substances, accumulated in deep water over protracted periods of time, can suddenly mix into the entire water column during the turnover period, causing water quality and plant management problems. For example, abundant nutrients from the hereto isolated deep portions of a lake can mix into near-surface water which in turn can fuel nuisance-level algae and plant growth.

- **A lake's current and past trophic status.** Lakes are commonly classified according to their degree of nutrient enrichment, or trophic status. The ability of lakes to support a variety of recreational activities, healthy fish, and other aquatic life communities is often correlated with the lake's degree of nutrient enrichment. Three terms are generally used to describe the trophic status of a lake: *oligotrophic* (nutrient poor), *mesotrophic* (moderately fertile), and *eutrophic* (nutrient rich) (see Figure 2.18). Each of these states can happen naturally. Lakes tend to shift to a more nutrient-rich state over time, a progression often referred to as "aging" (see Figure 2.19). However, if a lake rapidly shifts to a more eutrophic state, human-induced pollution is often responsible for this change. Under severe pollution and highly enriched conditions, a lake enters the "hyper-eutrophic" condition (see Figure 2.20). Hyper-eutrophic conditions do not commonly occur naturally and are nearly always related to human pollution sources.

- **Whether internal loading is occurring.** *Internal loading* refers to release of phosphorus stored in a lake's bottom sediment that occurs under low oxygen conditions associated with lake stratification. Phosphorus is typically not particularly soluble and often adheres to particles that settle to the lake bottom. When organic detritus and sediment settle to the lake bottom, decomposer bacteria break down the organic substances, a process that consumes oxygen. If lake-bottom waters become devoid of oxygen, the activity of certain decomposer bacteria, together with certain geochemical reactions that occur only in the absence of oxygen, can allow phosphorus from plant remains and lake-bottom sediment to dissolve into the water column. This allows phosphorus that is otherwise trapped in deep lake-bottom sediment to be released into lake water. This released phosphorus can mix into the water column during the next turnover period fueling plant and algae growth. In most lakes, phosphorus is the nutrient controlling overall plant and algal growth, and additional phosphorus can lead to increased plant and algal growth. If internal loading is a primary component of a lake's phosphorus budget, water quality management may focus on in-lake phosphorus management efforts in addition to preventing polluted runoff from entering the lake.

- **Lake tributary area/type.** Lakes with large tributary streams commonly receive larger sediment and nutrient loads than lakes that are fed primarily by precipitation or groundwater. The type of land use in the watershed greatly effects the pollutant loads carried by tributary streams. Lakes that are fed primarily by tributary streams are labeled drainage lakes.

Temperature, Oxygen, and Stratification

When a lake is stratified, shallow depths are considerably warmer, support abundant algae, and contain abundant oxygen. The thermocline is generally found somewhere between 10 and 30 feet below the surface, with the depth varying lake-to-lake, month-to-month, and year-to-year. Water within the thermocline rapidly cools with depth and often contains less oxygen than the epilimnion. Below the thermocline, water in the hypolimnion is much colder than water at the lake's surface and may not mix with the epilimnion until fall. Little sunlight penetrates past the thermocline; therefore, the deeper portions of the lake do not host significant photosynthetic activity and hence do not receive oxygen from plants. However, oxygen continues to be consumed by decomposition and other processes in the deeper portions of the lake. As a result, oxygen concentrations in the hypolimnion decline after the lake stratifies and cannot be replenished until the lake fully mixes during its fall turnover.

Temperature and oxygen concentration profiles were assembled from data spanning over 40 years. Temperature and oxygen concentration profiles suggest that Nagawicka Lake stratifies every year and remains stratified throughout the summer (see explanation of boxplot symbols on Figure 2.21 and profiles on Figure 2.22). The location and thickness of the thermocline vary month-to-month and year-to-year.

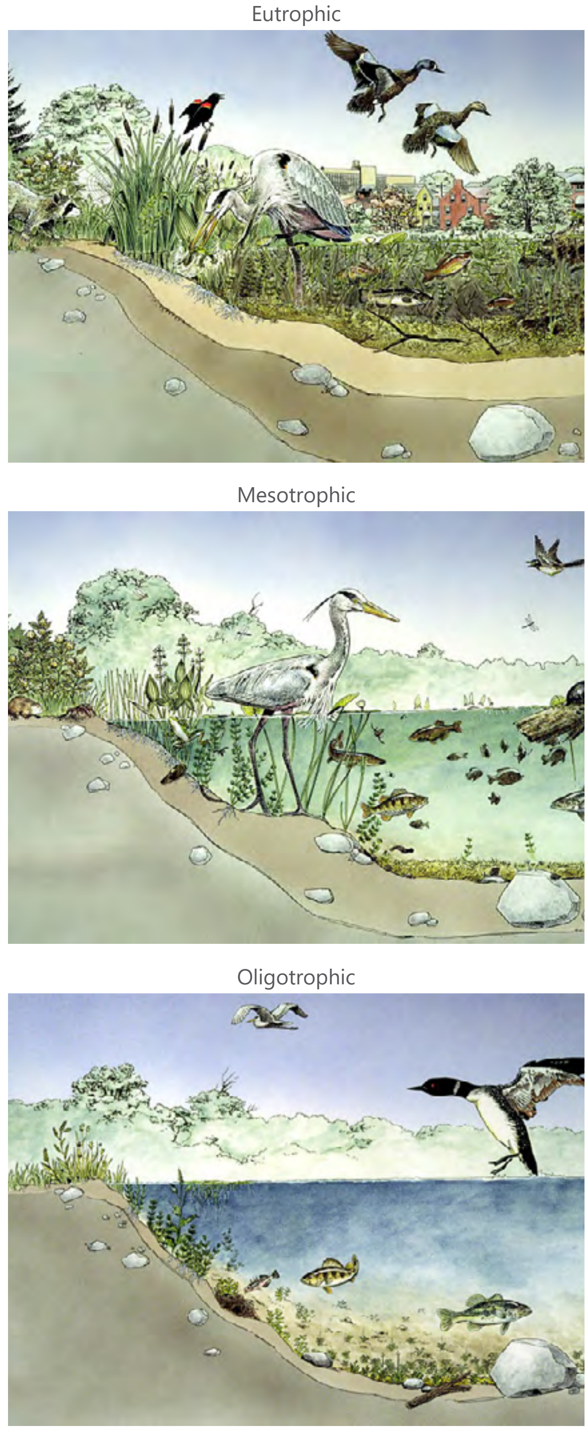
However, the summer thermocline is generally around 10 feet thick and is found somewhere between 20 and 40 feet below the Lake's surface.[60] As summer progresses, the epilimnion thickens and the thermocline is generally found deeper in the Lake. Denser, warmer water occasionally accumulates in the deepest areas of the Lake during winter, producing weak stratification.[61]

Temperature and oxygen profiles have noticeably changed over the period of available record. Figure 2.22 helps illustrate these changes by profiling the distribution of low, average, and high values of both temperature and oxygen concentration for two time periods: data collected between 1981 and 1999, and data collected between 2000 and 2017. These profiles indicate that the Lake's shallower areas are now much warmer in late spring before the Lake stratifies, and that Lake's shallow area are generally a bit warmer by late summer.

Based upon the available profiles, the deepest portions of Nagawicka Lake commonly have less oxygen than overlying cold water during winter, but all depths above 80 feet are fully capable of supporting aquatic life. Winter stratification breaks down in early spring, and the Lake is usually fully mixed by sometime in March or April. When fully mixed, oxygen concentrations vary little with depth and the Lake is capable of supporting aquatic life present at essentially all depths.

Nagawicka Lake's summer oxygen profiles are complex and are responding to many changes. The geochemistry of lake bottom sediment suggests that the hypolimnion was largely oxygenated until approximately 1910, a time period which also corresponds to higher organic matter deposition which is suggestive of more eutrophic Lake conditions.[62] Over recent years, the Lake has become less eutrophic.[63] Eutrophic lakes are more prone to oxygen depletion in their hypolimnia on account of heavy loads of organic matter settling to the lake bottom where they decompose and consume oxygen. All available oxygen profiles were measured after the Lake was well into its recovery from the significantly more eutrophic

Figure 2.18
Comparison of Lake Trophic Status



Source: UW-Extension Lakes Program and SEWRPC

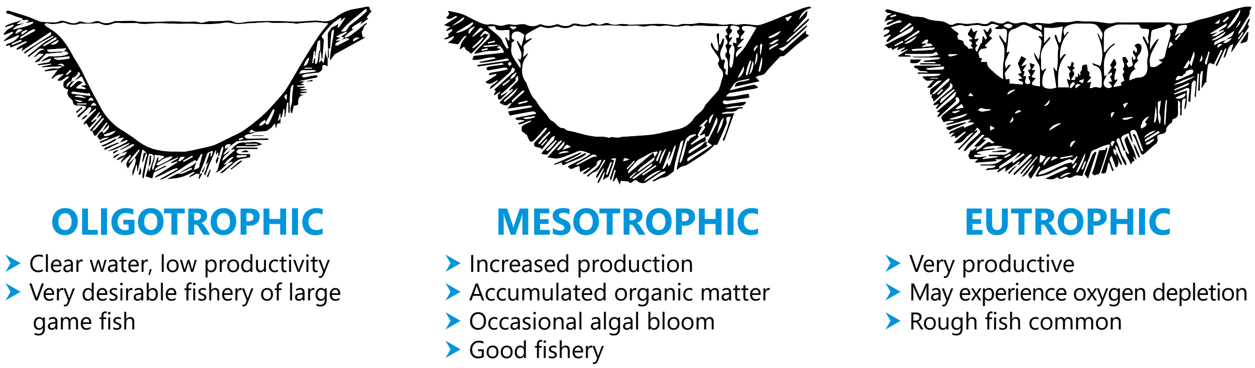
[60] *Temperature and dissolved oxygen measurements are collected at three-foot intervals. Prior to the year 2000, measurements were collected at five-foot intervals. The coarse nature of oxygen profile data makes it difficult to precisely determine where the thermocline lies in the water column. In the future, temperature and oxygen profiles should collect data at one- foot intervals in and near the suspected thermocline.*

[61] *Water achieves its maximum density in its liquid form at approximately four degrees Celsius, or 39 degrees Fahrenheit. Therefore, water near its freezing point temperature is more buoyant.*

[62] *P.J. Garrison,* Paleoecological Study of Nagawicka Lake, Waukesha County, *PBU-SS-993 2004, Bureau of Integrated Science Services – Wisconsin Department of Natural Resources, March 2004.*

[63] *Perhaps one of the largest changes influencing the Lake's productivity was the establishment of the DelaHart Water Pollution Control Commission during 1980, which diverted treated wastewater from the Upper Bark River and the Lake to points downstream of the Lake, significantly reducing nutrient loads.*

Figure 2.19
Lake Aging's Effect on Trophic Status



Source: Modified from B. Shaw, C. Mechenich, and L. Klessig, Understanding Lake Data, *University of Wisconsin-Extension, p. 5, 2004 and SEWRPC*

conditions experienced before 1980. As such, none of the profiles represent the oxygen distribution in the Lake during its most eutrophic phase.

Even though the Lake's most eutrophic period cannot be evaluated, Lake oxygen distribution measured during the period of available record demonstrate significant improvement. Perhaps the most prominent aspect of this promising trend is the improving oxygen concentration distribution in the Lake's hypolimnion (see Figure 2.23). During July, the volume of oxygenated hypolimnetic water has significantly increased. More strikingly, the Lake's hypolimnion, which was almost entirely anoxic by August before the late 1990s, now regularly contains large volumes of water with sufficient oxygen to support aquatic life throughout August. Unfortunately, oxygen concentrations in much of the hypolimnion still commonly fall to very low levels in the weeks immediately preceding fall turnover, a fact hindering establishment of a self-sustaining and biologically productive coldwater ecological niche in the Lake. Nevertheless, if the Lake's trophic status/productivity decreases a bit more in response to water quality initiatives, Nagawicka Lake has a substantial chance of maintaining oxygen concentrations supporting aquatic life in its hypolimnion throughout the year. Unfortunately, fall hypolimnetic oxygen concentration distributions during 2015 and 2017 were the worst noted since the late 1990s, breaking a long trend of improvement. Therefore, continued monitoring and an emphasis on improving water quality is warranted and highly desirable.

Throughout the period of available data (although becoming much more evident as the Lake's hypolimnetic oxygen concentration have increased), the Lake's oxygen profile exhibits a rather unusual metalimnetic oxygen minimum. In this situation, the Lake has a well-oxygenated epilimnion and hypolimnion, but low oxygen concentrations in the thermocline. When such conditions are observed, several factors may be at work in the Lake.[64] These factors are described in the following text.

- Organic matter and other materials that consume oxygen from the epilimnion or external sources settle to the metalimnion, where the sinking rate is slowed by temperature-induced water density differences. The accumulating organic matter actively decomposes in the metalimnion, while less biodegradable substances settle to the colder and less biologically active hypolimnion.[65] The concentration of biodegradation in the metalimnion depletes oxygen at this depth.

- In certain situations, zooplankton may mass in the metalimnion on account of abundant food sources. While this factor cannot account for metalimnetic anoxia, it can account for a tenth of oxygen demand in the metalimnion.

[64] *R.G. Wetzel,* Limnology, 2nd Edition*, Saunders College Publishing, 1983.*

[65] *Concentrated decomposition in the metalimnion may lead to high nutrient concentrations at this depth. In some instances, algae can grow profusely in this nutrient-rich zone. This can lead to abundant oxygen production in the metalimnion. If oxygen production exceeds the demands of decomposition, the metalimnion can become supersaturated with oxygen.*

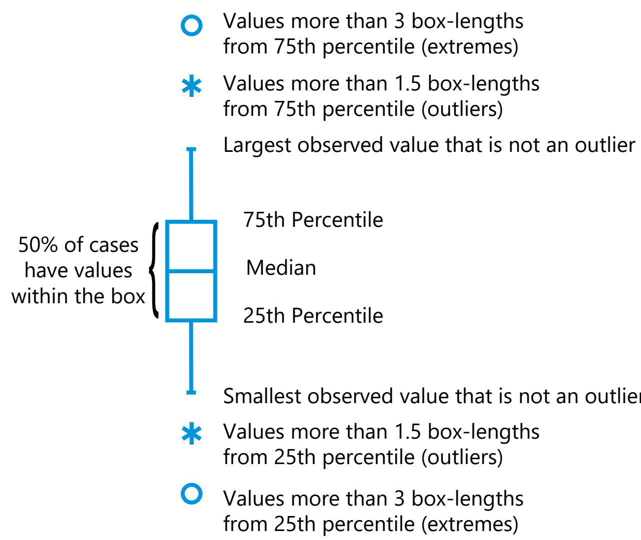
- Methane released from deep-water sediment can rise to the metalimnion and be oxidized in the warmer and more oxygenated metalimnion. This situation is fostered by the presence of dissolved nitrogen.

- In some cases, lake basin shape can contribute to high oxygen demand in the metalimnion. Degradation-driven oxygen consumption is often highest at the sediment-water interface. Should the metalimnion's depth range coincide with large expanses of lake bottom, oxygen demand in the metalimnion can be particularly high.

Figure 2.20
Example of a Hyper-Eutrophic Lake

Source: University of Minnesota, College of Natural Resources, 2003

Figure 2.21
Explanation of Symbols in Boxplot Figures



Source: SEWRPC

In Nagawicka Lake's case, methane oxidation and basin morphometry are not likely the primary factors driving oxygen depletion in the metalimnion. The Lake generally has an oxygenated hypolimnion, allowing methane oxidation to begin at deeper depths. Furthermore, the Lake does not have a pronounced depth bench in the depth range of the metalimnion (i.e., 20 to 40 feet). Instead, careful examination of oxygen profiles reveals that oxygen concentrations have been elevated in the metalimnion during early summer in many years, supporting the case for high productivity, zooplankton consumption, and organic matter decomposition in the hypolimnion.

The reduced volume of anoxic water in the hypolimnion has the potential to favorably influence the Lake's phosphorus budget and ecology. To illustrate this fact, roughly 350 acres of Lake bottom were typically in contact with anoxic water during August for the time period before 2000 (see Figure 2.24). Since 2000, roughly 85 acres of Lake bottom are typically exposed to anoxic water during August. Furthermore, the volume of anoxic water found in the Lake during a typical August has decreased by over 90 percent (see Figure 2.25). Since all profiles are collected at the deepest portions of the Lake, other conditions may exist at the same time in other parts of the Lake. For example, oxygen concentrations at similar depths may be differ throughout the Lake at the same moment in time. If areas of higher oxygen concentrations are present in other portions of the Lake in late summer, it is theoretically possible that aquatic organisms requiring cold, well oxygenated water could persist in Nagawicka Lake year-round.

Improving oxygen concentrations in the hypolimnion can positively influence the ability of the Lake to support desirable aquatic life, such as forage species and large gamefish. Before 2000, less than two-thirds of the Lake's bottom area was covered with water containing sufficient oxygen to support aquatic life during August. Data collected since the year 2000 reveals that over 92 percent of the Lake's total bottom area can now support aquatic life during typical August conditions. This finding has important implications for the Lake's capacity to potentially support a two-story fishery, where warm-water species can thrive in the upper layers of while cold-water species live in the oxygenated deeper portions of the lake. While the Lake is not currently a two-story fishery, continued improvements in hypolimnetic oxygen concentrations

Figure 2.22
Dissolved Oxygen and Temperature Seasonal Profile Data, Nagawicka Lake: Pre-2000 versus Post-2000

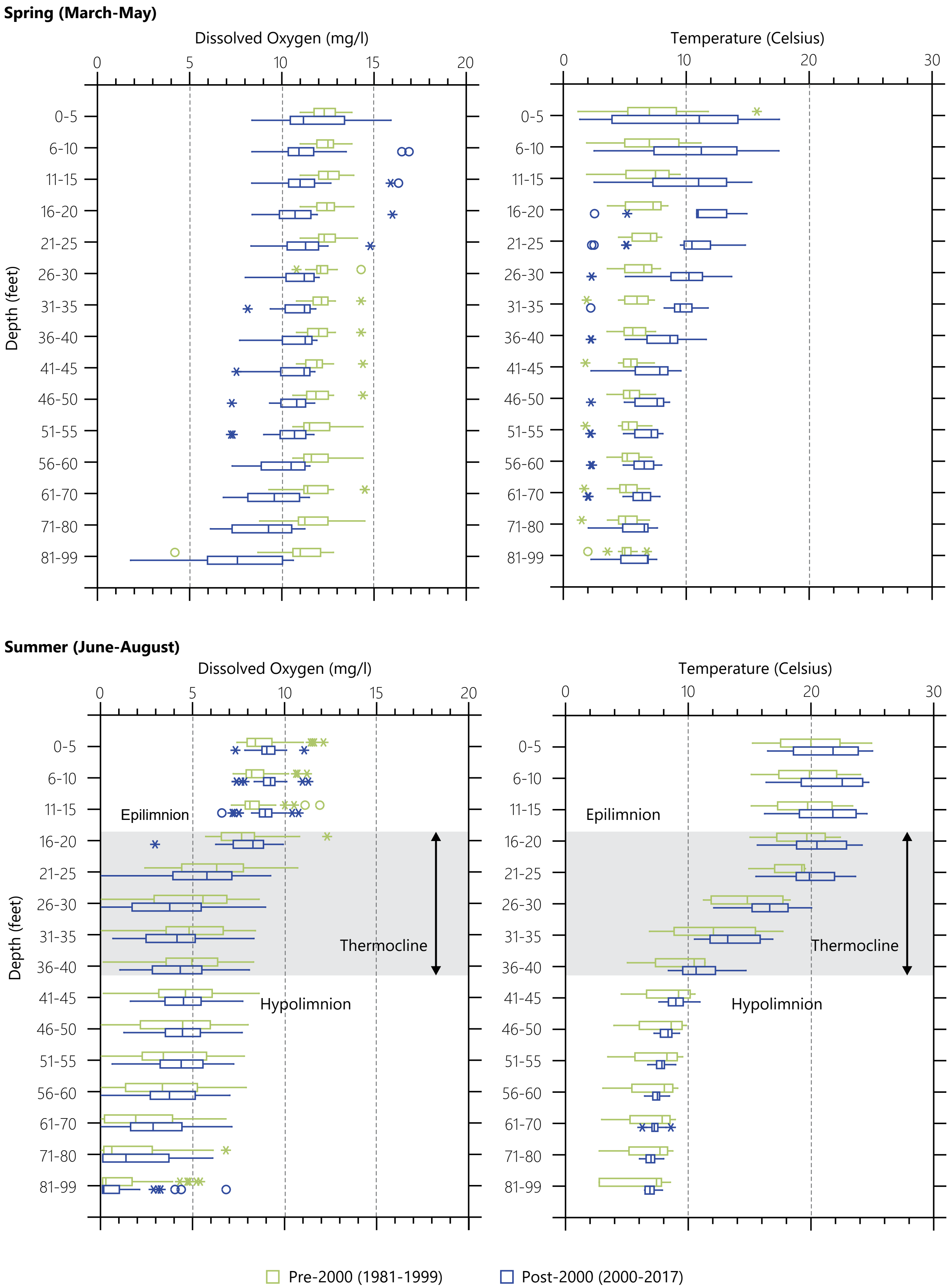
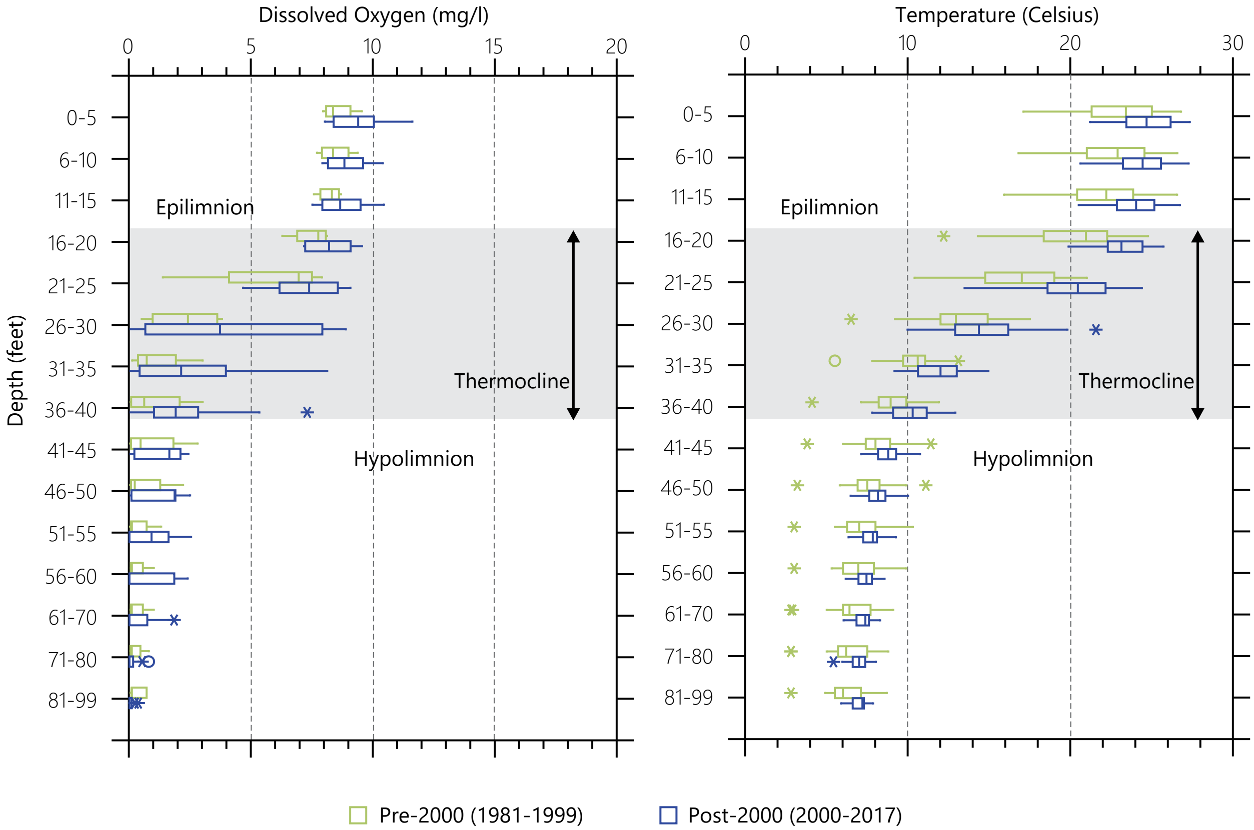


Figure 2.22 (Continued)

Fall (September-November)



Source: Wisconsin Department of Natural Resources and SEWRPC

would allow the Lake to support this unique ecosystem once again. The ecology of two-story fishery and its ramifications for sport fish in the Lake are further discussed in Section 2.6, "Fish and Wildlife."

As opposed to concentration, oxygen saturation relates measured oxygen concentration to the maximum theoretical oxygen concentration in equilibrium with the atmosphere at a given temperature. Values between 90 and 110 percent saturation are generally considered desirable for aquatic life, with values greater and less than this range being increasingly injurious to aquatic life. Oxygen saturation profiles (Figure 2.26) reveal that the near-surface waters of Nagawicka Lake are commonly supersaturated with oxygen during summer.[66] Oxygen supersaturation exceeds desirable ranges during July and August in some instances. Supersaturation is generally a result of abundant photosynthetic activity and is commonly related to human-induced nutrient enrichment.

Oxygen saturation values are typically uniform throughout the epilimnion. Since oxygen saturation values do not peak at the thermocline, nutrient enrichment driving supersaturation does not appear to be depend upon internal phosphorus loading. When internal phosphorus loading is a significant component of a lake's total phosphorus budget, oxygen supersaturation commonly peaks near the thermocline.

Although no night oxygen information is available, many water bodies exhibiting oxygen supersaturation during the day experience unacceptably low oxygen saturation levels at night. This condition is related to continued respiration and decomposition while photosynthesis is lacking. Low oxygen conditions are also stressful to aquatic organisms and can lead to fish stress and fish kills in summer. However, fish kills have

[66] *Supersaturation refers to a condition when the amount of dissolved substance exceeds the substance's maximum solubility in the solvent under normal circumstances. Such conditions are typically unstable. Dissolved gas comes out of water as bubbles. Fish exposed to oxygen saturations greater than 115 percent can develop bubbles in their tissues (a condition similar to "the bends" experienced by deepwater divers).*

Figure 2.23
Dissolved Oxygen and Temperature Profiles by Month for Nagawicka Lake: Pre-2000 and Post-2000

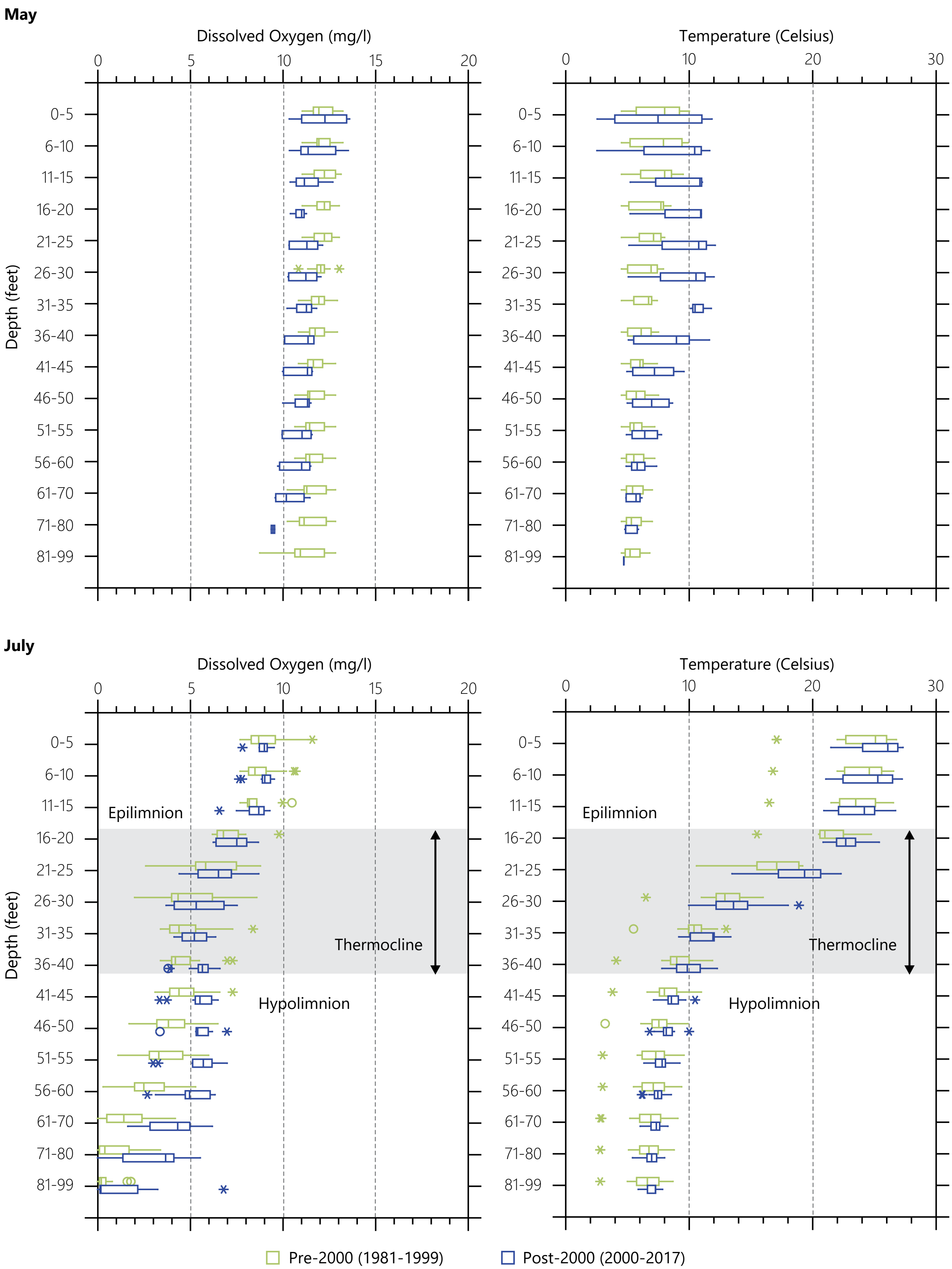
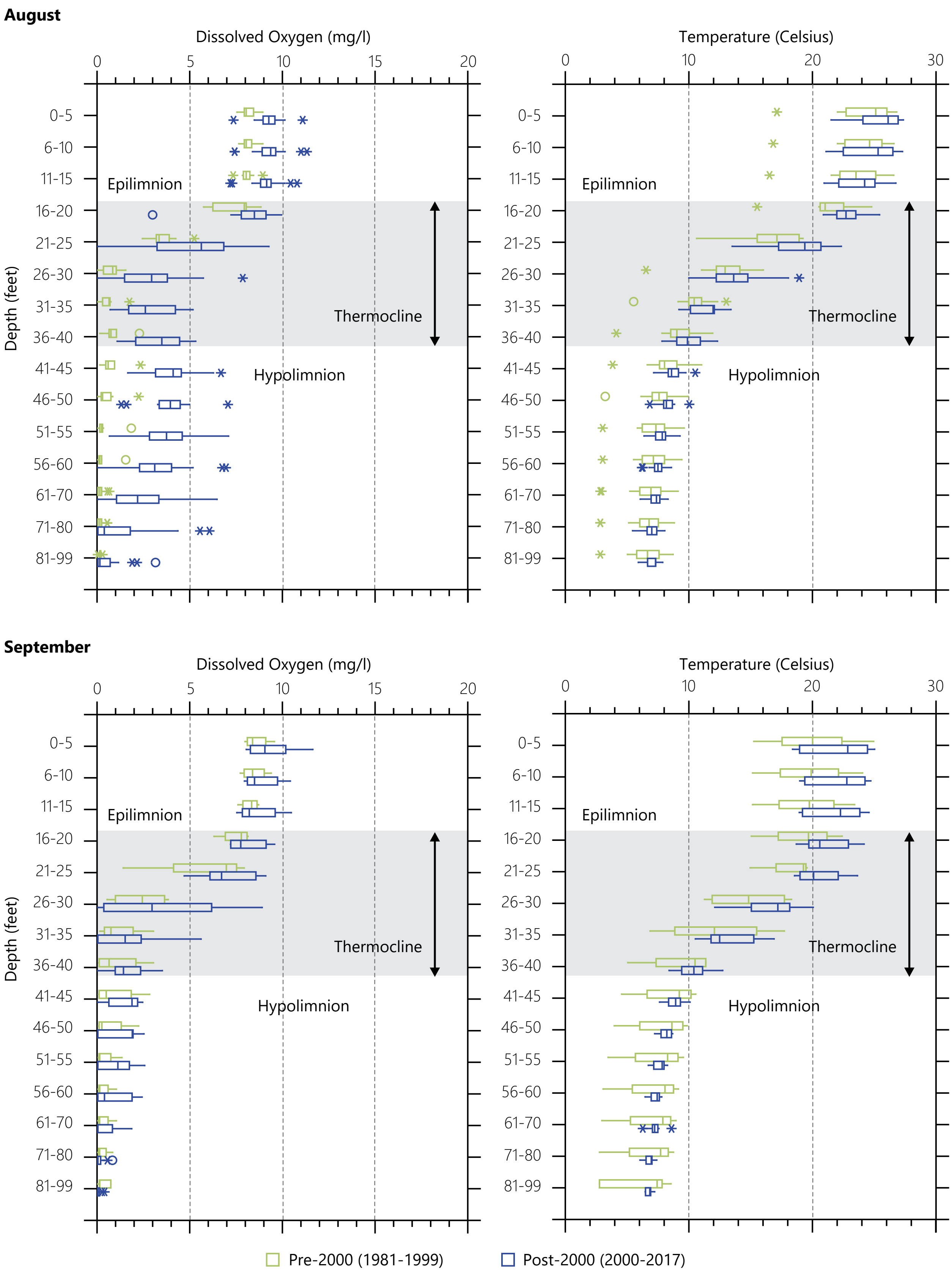
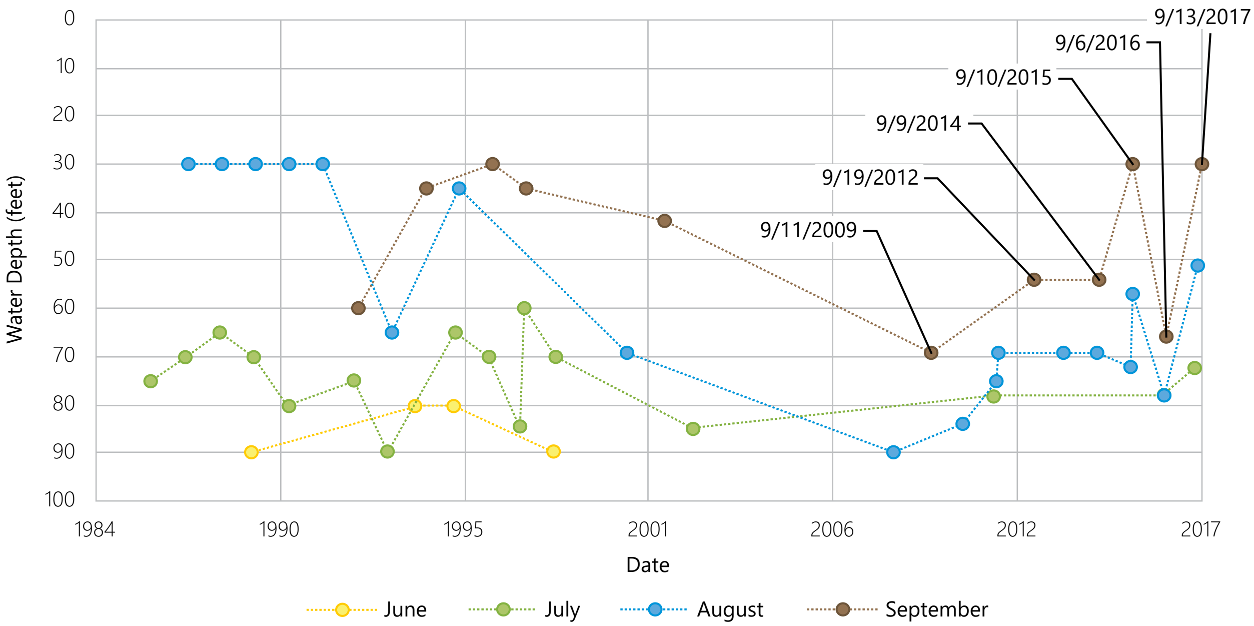


Figure 2.23 (Continued)



Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.24
Shallowest Occurrence of Hypolimnetic Anoxia from Profile Data Records by Month for Nagawicka Lake: 1981 – 2017



Source: Wisconsin Department of Natural Resources and SEWRPC

not been recently recorded in Nagawicka Lake. The oxygen concentrations in the epilimnion typically reach their daily minima immediately before sunrise.

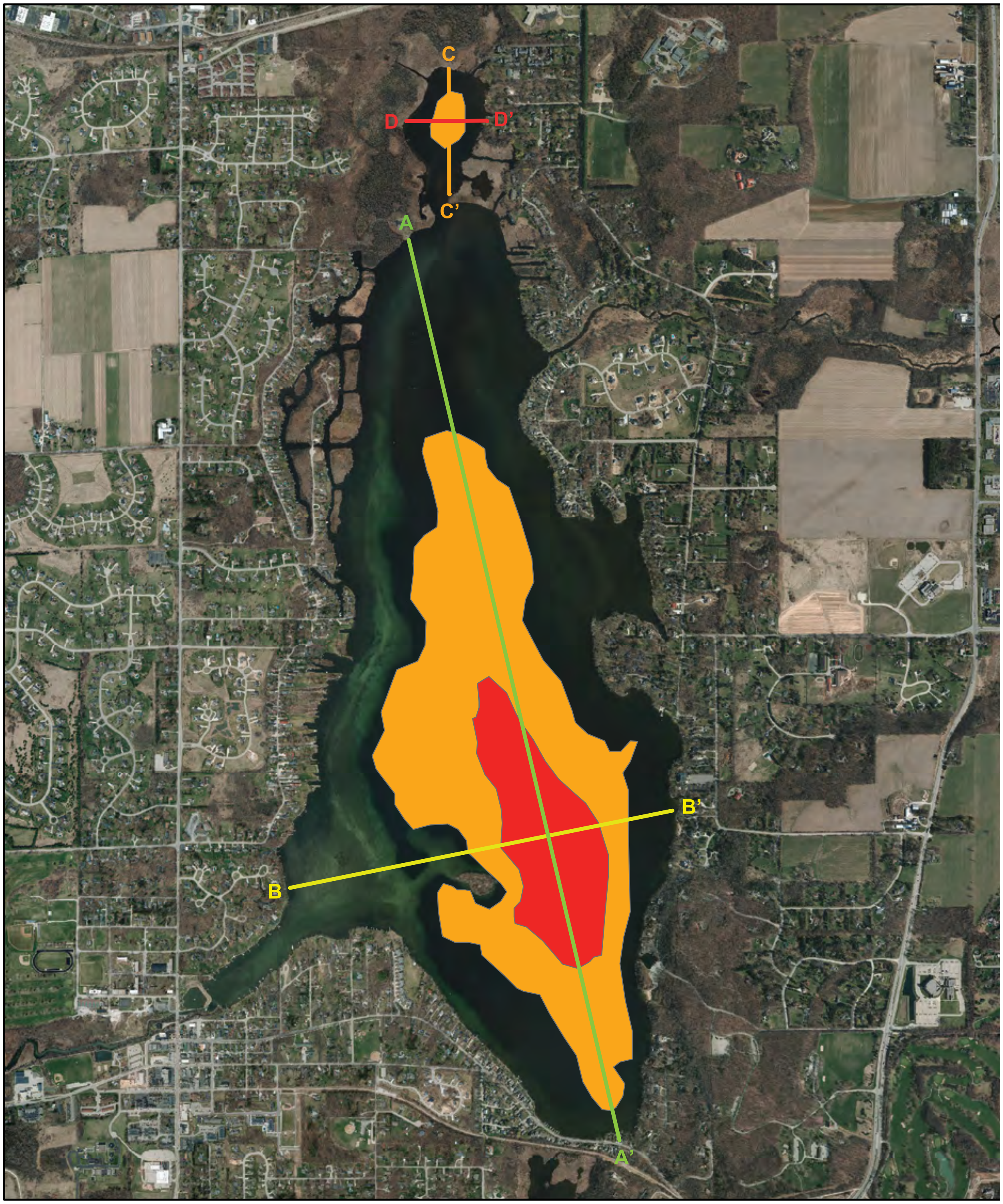
The available oxygen profiles provide an excellent way to evaluate past conditions, but data collection techniques could be enhanced to allow more thorough future examination. Some profiles terminate without reaching the Lake's bottom. Effort should be taken to collect oxygen and temperature data from the surface to the Lake's bottom in the deep hole area. Additionally, the sampling interval should be increased where water conditions are rapidly changing. This typically means within and near the thermocline. Measurements should be taken every foot in rapid change depths. Samples should also be collected more frequently and consistently. Ideally, values would be collected at least once every two weeks. Furthermore, the lack of pre-dawn oxygen information prevents evaluation of diurnal oxygen stress. Oxygen and temperature measurements should be collected at first light (before sun up) several times during the summer. Finally, it would be wise to supplement the deep hole oxygen/temperature profiles with profiles collected at other locations in the Lake. These locations can vary but must be accurately mapped for future evaluation and comparison.

Secchi Depth

Secchi depth, a measure of water clarity, is often used as an easy-to-measure and understand water quality indicator. Water transparency can be affected by physical factors such as water color and suspended particles, and by various biological factors including seasonal variations in planktonic algal populations living in a lake's water column. Secchi depth is often highest during winter, indicating high water clarity, and lowest during summer when biological activity is most active. Secchi depths were collected at the "deep hole", or deepest area of the Lake (Figure 2.27). Measurements have been taken at the Deep Hole since 1973. However, summer measurements only began in the early 1980s. Summer (June through August) measurements are what are generally used to compare water clarity and evaluate trophic status. Overall, Secchi depths indicate fair to good water quality, with recorded values averaging 9 feet during the summer months.[67] Water clarity has slightly increased over the period of record. The variations in water quality may be at least partially related to sampling protocol. For example, during some years, only one secchi reading was taken the entire year, and this reading could represent an extreme condition.

[67] *It is important to note that although only summer secchi measurements are used to evaluate water quality changes, secchi depths in the Lake typical of summer months commonly continue well into September.*

Figure 2.25
Extent of Nagawicka Lake's Bottom in Contact with Anoxic Water



MEAN AUGUST EXTENT OF BOTTOM SEDIMENT IN CONTACT WITH ANOXIC WATER

PRE-2000s MEAN

POST-2000s MEAN

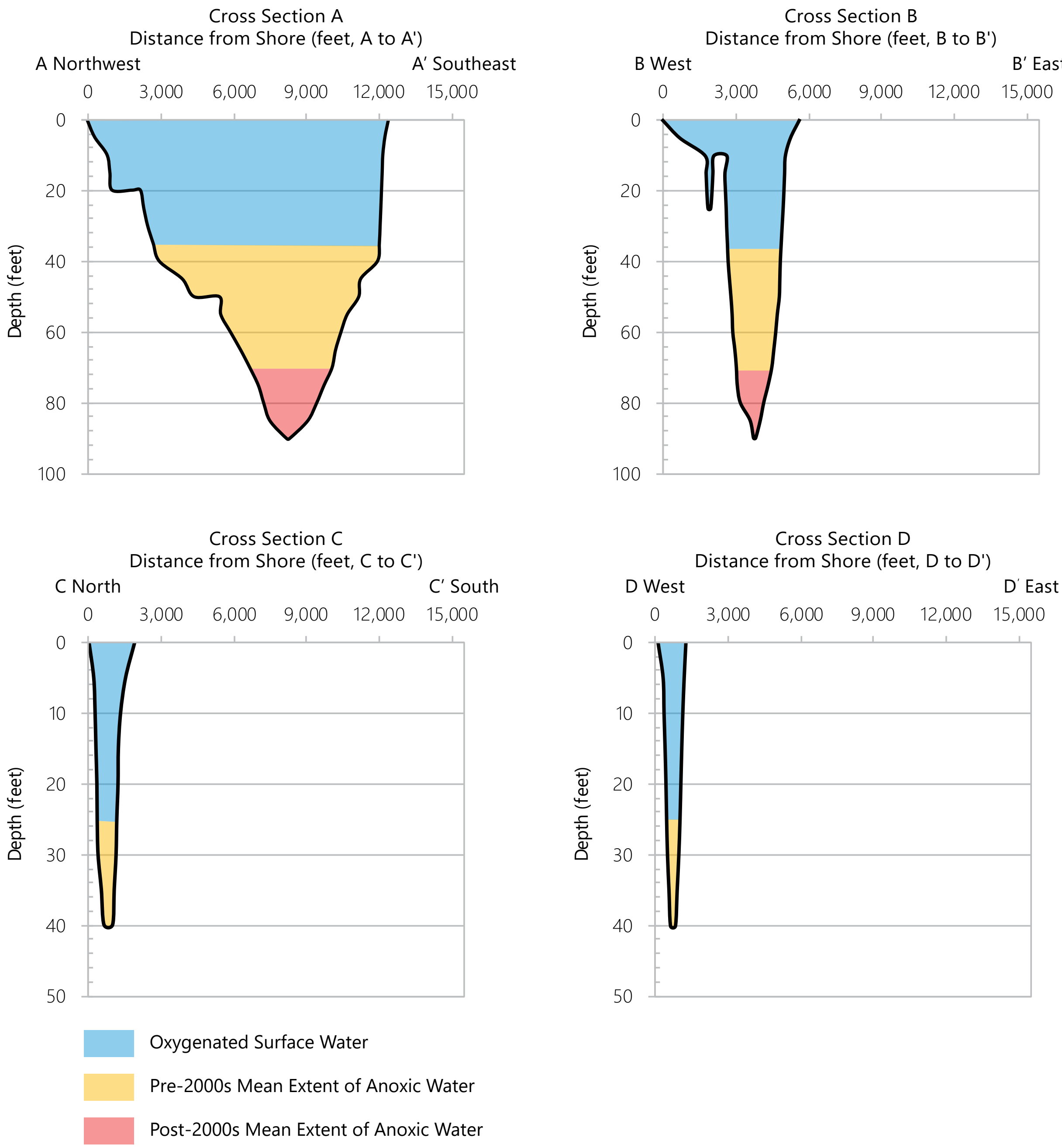
CROSS SECTION A
CROSS SECTION B
CROSS SECTION C
CROSS SECTION D

DATE OF PHOTOGRAPHY: APRIL 2015

N

Source: SEWRPC, Mapping Specialists 2002/(2006)

Figure 2.25 (Continued)

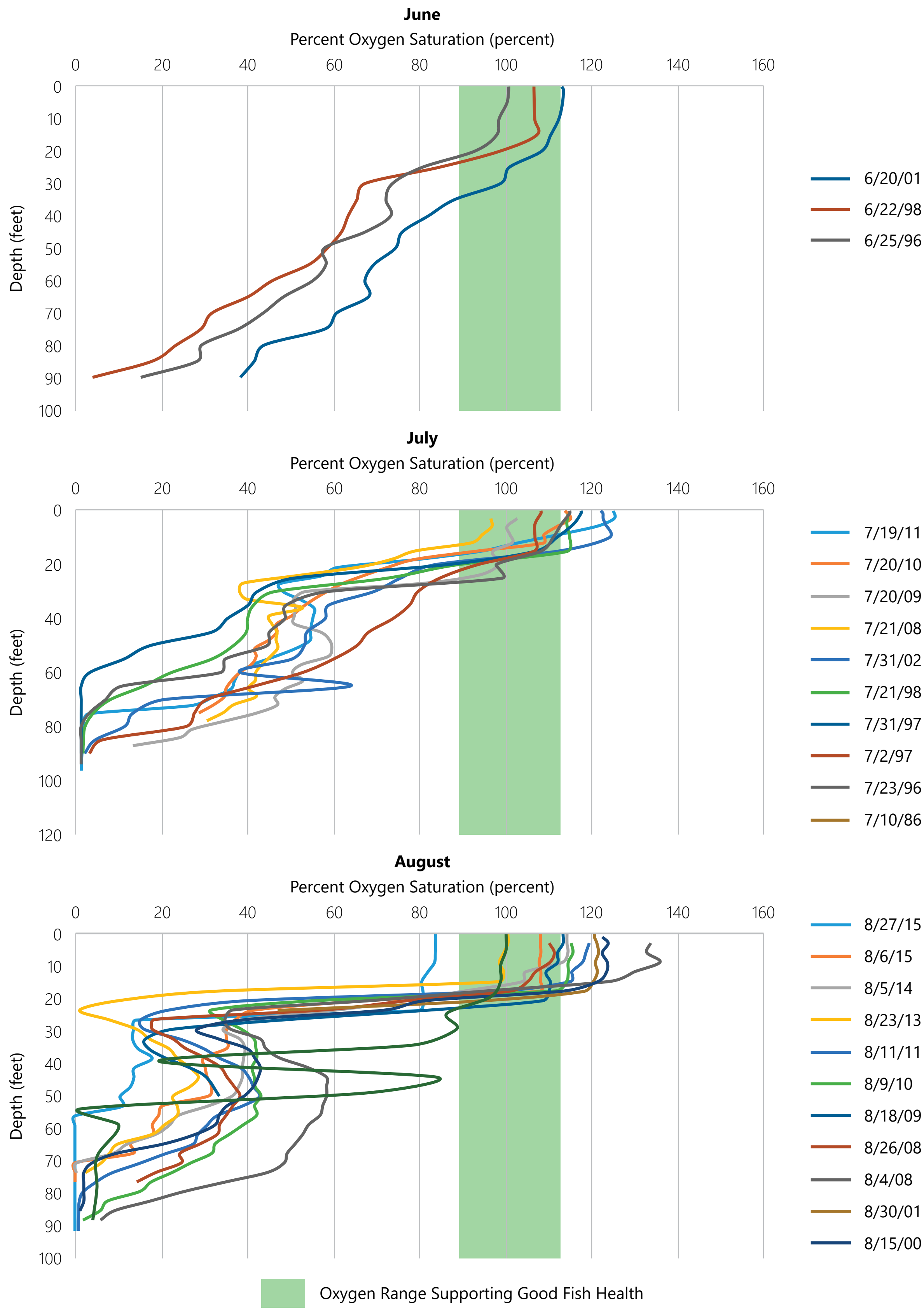


Source: Wisconsin Department of Natural Resources and SEWRPC

While on-the-water secchi measurements are most accurate, they are commonly limited to only one point in the Lake. Satellite water clarity estimates allow water clarity differences throughout the Lake to be noted and studied. Water clarity estimates for the entire Lake have been derived from satellite imagery for four years (see Figure 2.28). Identifying reasons for water clarity differences requires consideration of weather, runoff patterns, and other factors. Whatever the reason, the satellite imagery demonstrates that the center of the Lake is most clear, and that the most turbid areas occur in locations within, or near, riparian wetlands and shallow bays. No indication of cloudy water near the mouth of the Bark River is perceivable. In fact, the June 2013 image reports clearer water at the point where the Bark River enters the Lake.

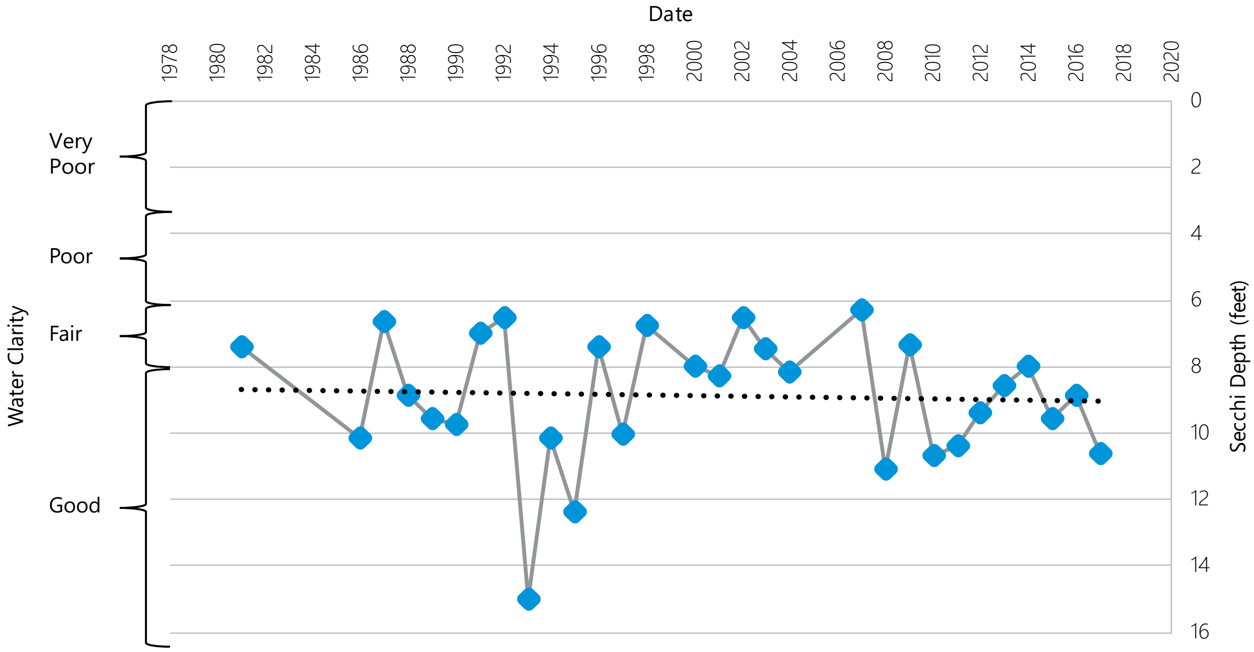
The zebra mussel (*Dreissena polymorpha*) has been shown to affect water clarity. This nonnative species of shellfish rapidly colonizes nearly any clean, stable, flat underwater surface, artificial or natural. Massive

Figure 2.26
Monthly Summer Oxygen Saturation Profiles, Nagawicka Lake



Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.27
Nagawicka Lake Average Annual Summer Water Clarity at the Deep Hole: 1981 – 2017



Source: Wisconsin Department of Natural Resources and SEWRPC

colonies have become a significant nuisance in some lakes. Veligers (zebra mussel larvae) were identified in Nagawicka Lake in 1998. Zebra mussels remove particulate matter from the water column and have the tendency to improve water clarity. Secchi depth measurements did not significantly increase after 1998 suggesting that zebra mussels are having little influence on the clarity (and plankton abundance) in Nagawicka Lake.

Nutrients

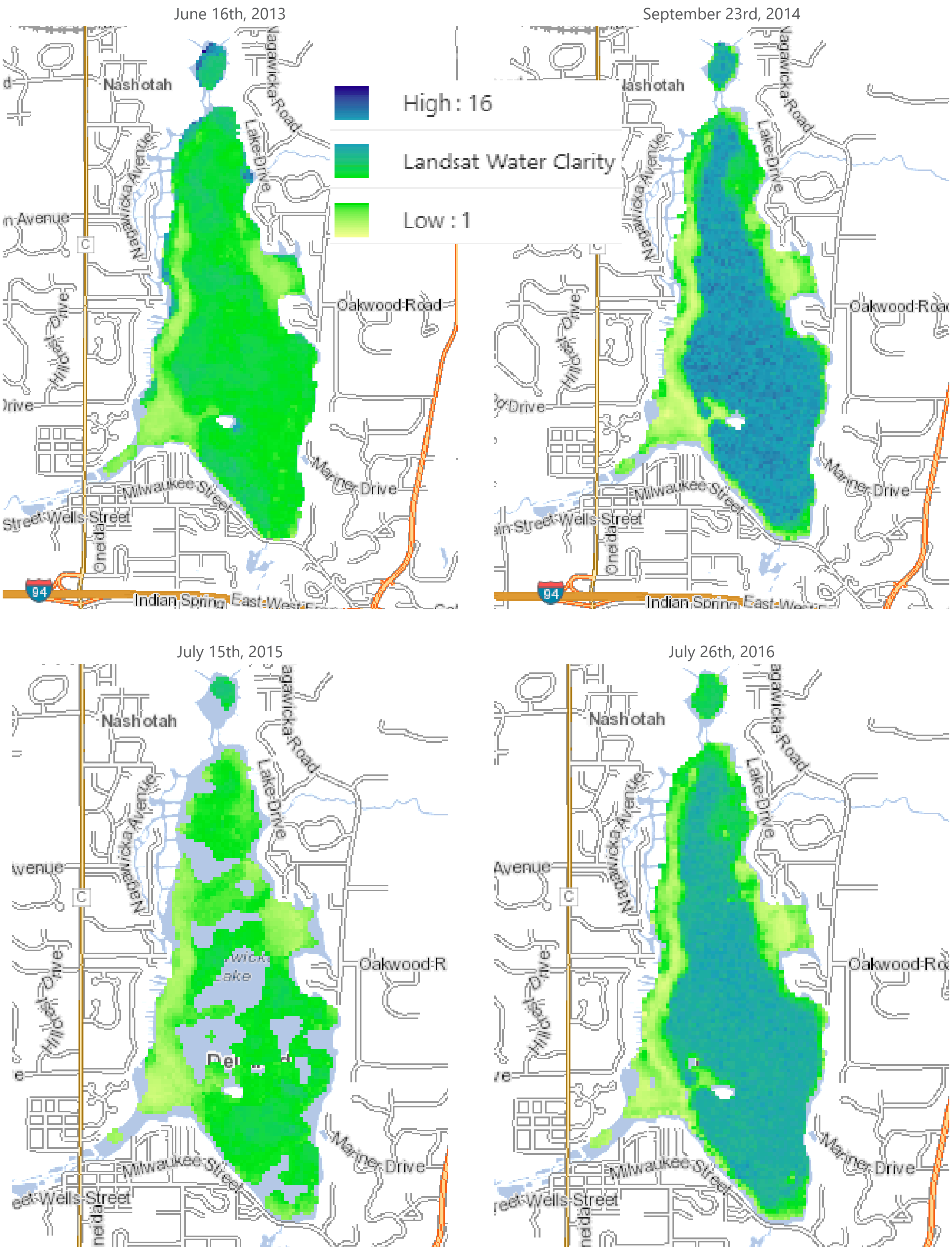
Nitrogen and phosphorus are the two compounds that commonly limit growth of aquatic plants and algae. The amount of phosphorus (P) limits algal growth in most Wisconsin lakes. However, in some lakes, the amount of nitrogen (N) limits algal growth. Awareness of which nutrient constrains algal growth can be important when making management decisions. In general, when the concentration ratio of total nitrogen (N) to total phosphorus (P) is 15:1 or greater, available phosphorus limits algal growth. Conversely when this proportion is less than 10:1, nitrogen concentrations limit plant growth. Ratios between 15:1 and 10:1 are considered transitional.

Available data reveal that Nagawicka Lake is severely phosphorus limited (Figures 2.29 and 2.30). During spring turnover, N/P ratios typically average in the high fifties and range from as low as 36:1 to as high as 100:1. N/P ratios differ seasonally and by the depth from which samples are drawn while the Lake is stratified. Nagawicka Lake has been phosphorus limited throughout recent history, but historical data from a 1974 USEPA study shows that the Lake was previously nitrogen limited, with an N/P ratio of 8:1.[68]

When Nagawicka Lake is fully mixed in the spring, phosphorus concentrations are similar throughout the Lake, averaging 0.028 mg/L over the period of record (Figure 2.31) Spring turnover total phosphorus concentrations were very high in the 1970s, ranging from 0.8 to 0.11 mg/L. Little data is available for the period immediately following the time when wastewater treatment plant effluent was diverted from the Lake and when most livestock operations within the watershed ceased. Phosphorus concentrations stabilized by the late 1980s and have since averaged around 0.013 mg/L.

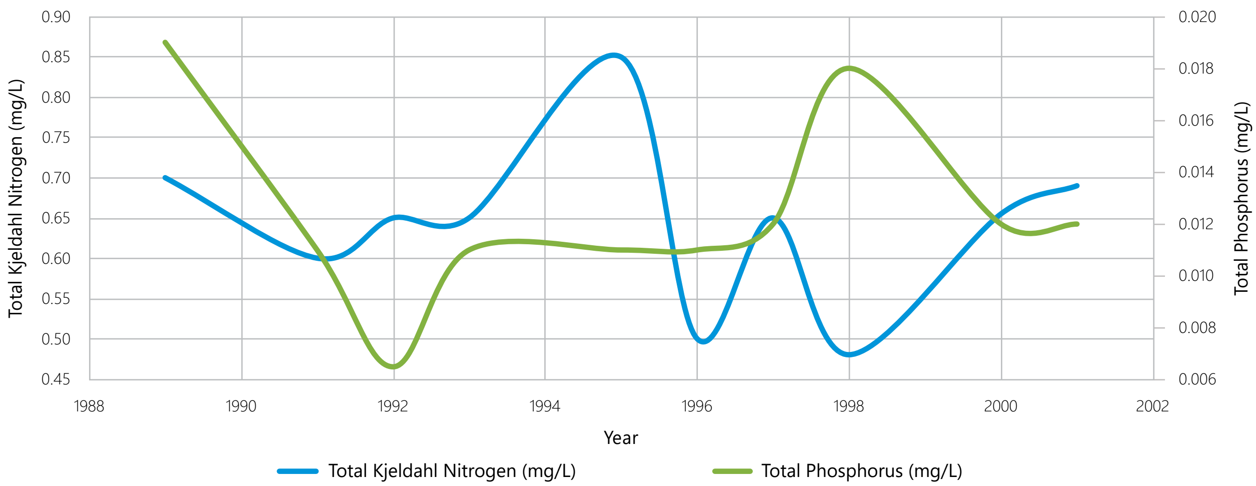
[68] *EPA Region V Working Paper No. 43,* Report on Nagawicka Lake, *U.S. Environmental Protection Agency National Eutrophication Survey, November 1974.*

Figure 2.28
Satellite Derived Water Clarity, Nagawicka Lake



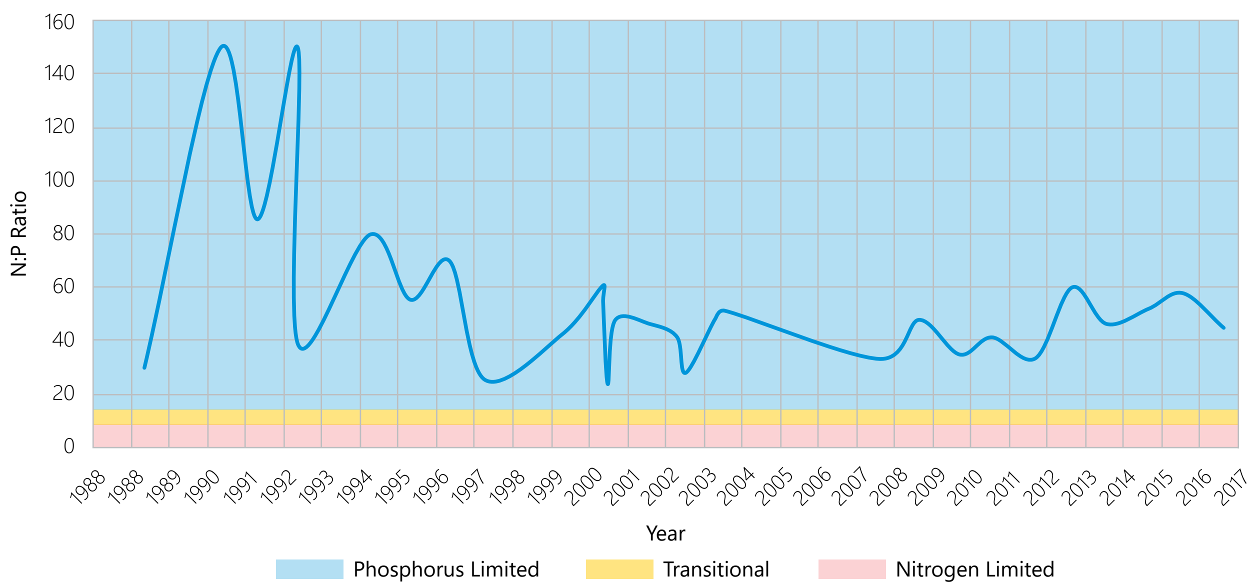
Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.29
Spring (Fully Mixed) Nitrogen and Phosphorus Trends: 1989 – 2001



Source Wisconsin Department of Natural Resources and SEWRPC

Figure 2.30
Surface Nitrogen: Phosphorus Ratios in Nagawicka Lake



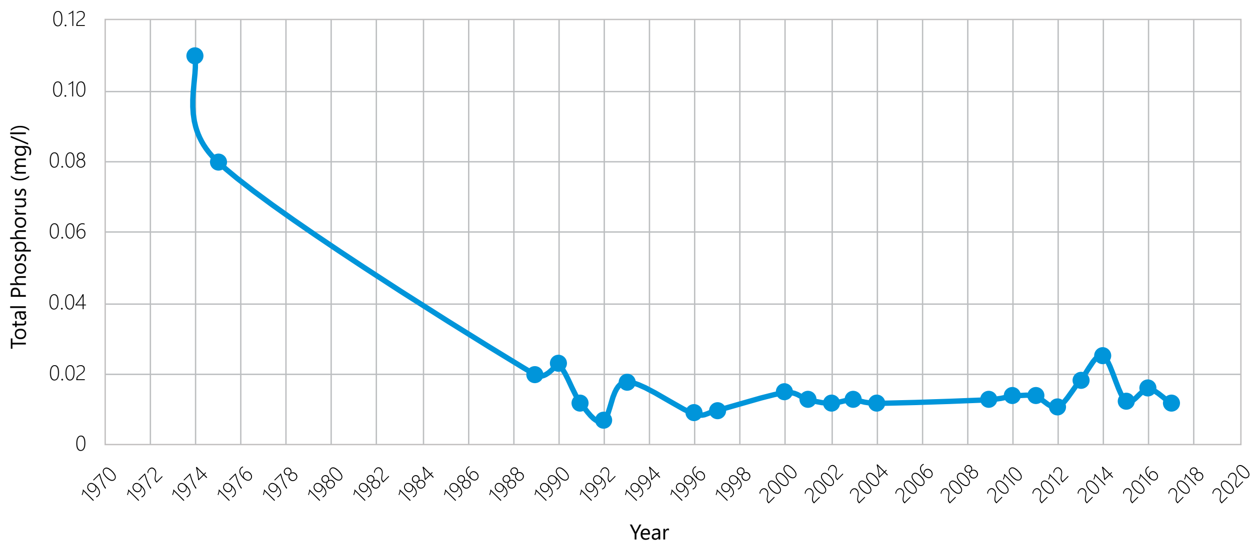
Source: Wisconsin Department of Natural Resources and SEWRPC

Phosphorus concentrations vary widely within Nagawicka Lake when the Lake is stratified (Table 2.13). Samples collected near the surface during the growing season commonly have the lowest phosphorus concentrations, averaging 0.013 mg/L, a value just slightly below the Chapter NR 102 total phosphorus limit of 0.015 mg/L for stratified two-story drainage lakes (see Figure 2.32).[69] This value is also below the recreational impairment threshold of 0.030 mg/L for such lakes mandated by Chapter NR 102 of the *Wisconsin Administrative Code*.

Phosphorus concentrations reach their highest values in the deeper waters of Nagawicka Lake during warm season stratification (Table 2.13). Samples drawn from the Lake's hypolimnion during the summer months commonly contain phosphorus concentrations many times higher than near-surface lake water, with values

[69] *Wisconsin Department of Natural Resources*, Wisconsin 2020 Consolidated Assessment and Listing Methodology (WisCALM) Clean Water Act Section 305(b), 314, and 303(d) Integrated Reporting, *April 2019*.

Figure 2.31
Spring (Fully Mixed) Phosphorus Trend, Nagawicka Lake: 1973 – 2017



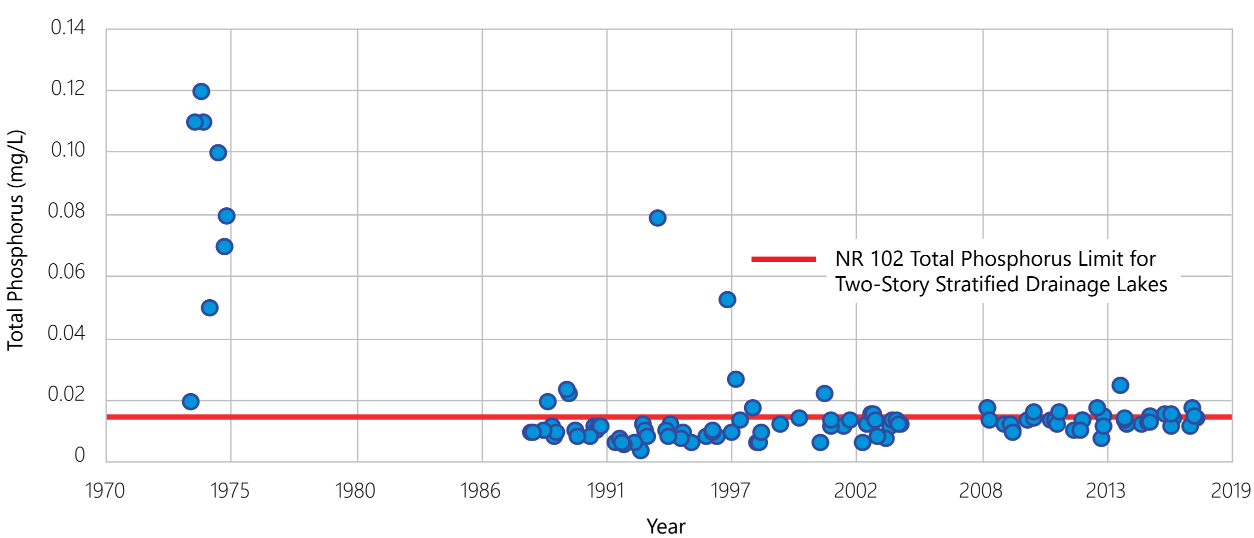
Source: Wisconsin Department of Natural Resources and SEWRPC

Table 2.13
Average Epilimnion and Hypolimnion Summer Phosphorus Concentrations

Month	Average Epilimnion Phosphorus Concentration (mg/L)	Average Hypolimnion Phosphorus Concentration (mg/L)
June	0.017	0.068
July	0.013	0.092
August	0.013	0.133
September	0.012	0.182

Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.32
Summer Near-Surface Total Phosphorus Concentrations, Nagawicka Lake: 1973 – 2017



Source: Wisconsin Department of Natural Resources and SEWRPC

averaging 0.12 mg/L, and values ranging from 0.07 mg/L to 0.18 mg/L over the period of available record. Phosphorus concentrations rapidly increase as the Lake stratifies, reaching their maxima during September.

Phosphorus Sequestration

In areas of mineral-rich calcareous groundwater ("hardwater"), marl deposits often exist on the beds of lakes fed by groundwater seeps and springs. Marl is composed chiefly of calcium carbonate, clays and silts, and some organic detritus. The formation of marl can co-precipitate dissolved phosphorus which helps reduce phosphorus concentrations in the water of some lakes. In such instances, co-precipitated phosphorus is deposited as a stable mineral upon the lake bed. Over fifty percent of a lake's external phosphorus loading is typically retained in lake-bottom sediment. The actual amount retained in a lake varies widely with watershed and lake characteristics, but up to ninety percent can be retained in some instances.[70] Studies completed by the USGS conclude that Nagawicka Lake has a strong ability to sequester phosphorus, with 87 percent of the phosphorus entering the Lake retained in lake-bottom sediment.[71,72]

Marl is commonly formed as a byproduct of growth of certain algae species (e.g., muskgrass), accumulates on plant stems and leaves, and ultimately falls to the lake bottom as the algae grows and dies. Photosynthesis increases water pH in the immediate vicinity of the plant, enhancing precipitation of calcite. Since enriched lakes generally support more algae, enriched lakes can have a self-reinforcing positive feedback loop to sequester more phosphorus. However, calcite/phosphorus minerals may become less stable at high pH ranges, potentially reducing the effect of this feedback loop. Muskgrass, which is a dominant species in Nagawicka Lake, has ability to sequester phosphorus in the Lake.

Research in Europe has found that although marl lakes are resistant to phosphorus enrichment and eutrophication, the bottom-dwelling species of algae that promote marl production can be sensitive to long-term phosphorus enrichment. Decreased water clarity associated with higher phosphorus concentrations can decrease the depth to which bottom dwelling algae can grow, in turn decreasing the extent of marl-precipitating algae near the lake bottom. Less marl precipitation increases overall dissolved phosphorus in the lake which in turn fosters higher abundance of free-floating algal species. These further decrease water clarity, forming a self-reinforcing negative loop that eventually destabilizes the beneficial marl formation process. Some formerly clear European marl lakes that had successfully buffered heavy, long-term external phosphorus loads went through rapid change after the lake's buffering capacity was exceeded and are now eutrophic lakes with low water clarity.[73] This illustrates how the algae-based phosphorus sequestration process is vulnerable to excessive long-term high phosphorus loads, demonstrating the importance of reducing external phosphorus loads to lakes and maintaining healthy native aquatic plant communities. Phosphorus sequestration may be able to be enhanced if water clarity improves, reinforcing this beneficial process.

Marl formation/phosphorus co-precipitation depends upon continued discharge of mineral-rich groundwater to springs and seeps on the Lake bottom. If the supply of groundwater is reduced, the vigor of hardwater algae is reduced, compromising the phosphorus sequestration cycle. Therefore, the Lake's groundwater supply must be protected to ensure that phosphorus sequestration remains active if sequestration is, in fact, occurring.

In Wisconsin, phosphorus is sequestered in lake-bottom sediment with calcite (as described above) or with iron. Unlike calcium minerals, iron-bound phosphorus is sensitive to the concentration of oxygen in adjacent water. Under low oxygen conditions, iron-bound phosphorus minerals dissolve and release plant-available phosphorus to the water column. This source of phosphorus, an important component of what is commonly referred to as internal loading, can be a significant contributor to the total phosphorus available to algae in lakes, especially in lakes that have fewer sources of external phosphorus during the growing season. For this reason, the presence of anoxic water can profoundly influence the nutrient dynamics of certain lakes.

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[70] *L. Lijklema, "Phosphorus accumulation in sediments and internal loading,"* Hydrological Bulletin *20(1): 213-224, 1986.*

[71] *Garn, 2006,* op. cit.

[72] *D.M. Robertson, H.S. Garn, and W.J. Rose, "Response of Calcareous Nagawicka Lake, Wisconsin, to Changes in Phosphorus Loading,"* Lake and Reservoir Management *23(3): 298-312, 2007.*

[73] *E. Wiik, H. Bennion, C.D. Sayer, T.A. Davidson, S. McGowan, I.R. Patmore, and S.J. Clarke, "Ecological sensitivity of marl lakes to nutrient enrichment: Evidence from Hawes Water,* UK", Freshwater Biology, *60(11): 2226-2247, 2015.*

Internal Loading

Phosphorus, under oxygenated conditions, is tightly bound to solids and large amounts of phosphorus are commonly found in lake-bottom sediment. However, when oxygen is absent, geochemical reactions can occur that release phosphorus from the bottom sediment into the water column. The amount of sediment exposed to anoxic water is controlled by the shape of the lake basin. For example, even though two lakes may have equivalent maximum depths, a lake with broad shallow areas and a small deep hole has less deep-water bottom sediment area when compared to a lake of similar maximum depth that is deep over most of its extent. Since sediment exposed to anoxic water can release phosphorus into the water column, lakes with more deep-water sediment area are more susceptible to significant phosphorus internal loading. Moderate depth/size stratified lakes are among the most prone to internal phosphorus loading. Such lakes lack large water volumes, and, hence, have comparatively little stored oxygen in the hypolimnion, making them prone to anoxia.

Water chemistry, lake type, and bathymetry information yield crosslinking evidence that Nagawicka Lake occasionally supports conditions that favor internal phosphorus loading as shown in Table 2.14. Before the year 2000, waters below about 36 feet contained little to no oxygen by August. Since 2000, waters below 71 feet contain little to no oxygen during August. Before 2000, waters below 40 feet were largely anoxic by September. Since 2000, anoxic water was generally encountered substantially deeper during September (i.e., 49 feet). The composition of Lake-bottom sediments in deeper portions of the Lake is likely to be predominantly a flocculent organic silt, which commonly contains significant concentrations of phosphorus.

Internal phosphorus mass loading attributable to dissolution from seasonally anoxic bottom sediment can be estimated using whole-lake total phosphorus water concentrations determined during fully mixed conditions occurring during or shortly after spring turnover (see Figure 2.31), from lake water samples collected from the hypolimnion during the stratified conditions occurring in summer (Table 2.13), and assuming that little mixing between the epilimnion and hypolimnion occurs after the Lake stratifies. As was discussed earlier in this section, the volume of anoxic water and area of lake bottom exposed to anoxic water during summer is much reduced. The available data suggests that improving water quality has decreased the mass of phosphorus contributed during summer (June, July, and August) by 98 percent.[74]

Phosphorus released to the hypolimnion is not directly available to most algae growing in a lake, since little sunlight penetrates to these depths. The thermocline acts as a partial barrier to circulation, allowing some phosphorus to migrate to shallower areas. For this reason, the highest levels of algal productivity are often found just above the thermocline in lakes with phosphorus internal loading. Mixing caused by wind and/or seasonal turnover can cause large concentrations of phosphorus from the hypolimnion to suddenly mix with surface water. This can lead to algal blooms. With the significant reduction in internal loading documented by water chemistry data, the chance of sudden algal blooms stemming from internally loaded phosphorus is significantly reduced.

Alkalinity

Alkalinity is a measure of water's ability to neutralize acid. Lakes in Southeastern Wisconsin are generally well buffered by highly alkaline water. In the Region, alkalinity correlates with water hardness, and is therefore correlated with marl precipitation and phosphorus sequestration. Rainwater is essentially devoid of alkalinity, and most alkalinity is derived from dissolution of minerals in sediments. For this reason, groundwater is the major source of alkalinity to most lakes and rivers in Southeastern Wisconsin, and groundwater along with native aquatic plants drive the phosphorus sequestration.

Alkalinity values measured from water samples collected from the Lake are plotted over time in Figure 2.33. As can be seen from this graph, alkalinity values in the Lake are slowly declining, a situation that could eventually compromise the Lake's extremely important phosphorus sequestration capacity. The reason for this decline is not clear but may likely be related to reduced volumes of groundwater entering the Lake.

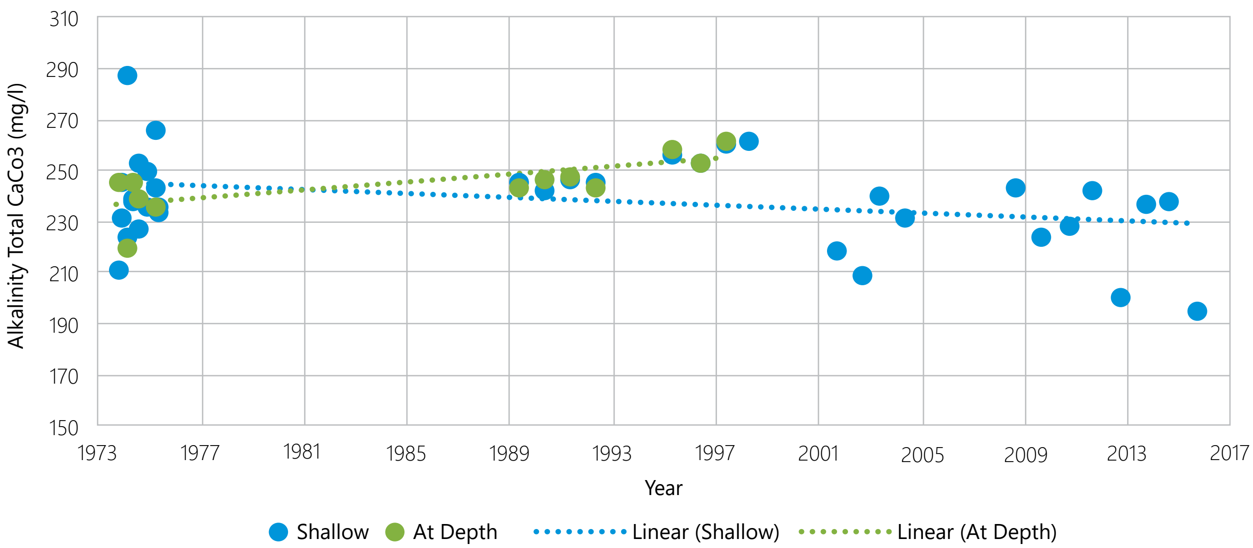
[74] *Water quality data collected before the year 2000 suggests that approximately 2,700 pounds of phosphorus were contributed to the Lake by internal loading through August. Data collected after 2000 suggest that only 48 pounds of phosphorus are contributed to the Lake by internal loading through August. This reduction in summer phosphorus loading is equivalent to the annual mass of phosphorus contributed to the Lake by the Upper Bark River as quantified by the U. S. Geological Survey.*

Table 2.14
Change in Nagawicka Lake's Anoxic Hypolimnia: Pre-2000 Versus Post-2000 Conditions

	Pre-2000			Post-2000			
Month	Total Sampling Events (1981-1999)	Sampling Events Demonstrating Deepwater Anoxia (percent of total sample dates)	Mean Depth to Anoxic Water (feet)	Total Sampling Events (2000-2017)	Sampling Events Demonstrating Deepwater Anoxia (percent of total sample dates)	Mean Depth to Anoxic Water (feet)	**Difference in mean depth to the upper limit of anoxic hypolimnetic water**
June	11	4 (36)	85	1	0 (0)	none	--
July	13	12 (92)	73	8	4 (50)	78	-5 feet
August	7	7 (100)	36	14	11 (79)	71	-35 feet
September	4	4 (100)	40	7	7 (100)	49	-9 feet

Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.33
Alkalinity in Nagawicka Lake



Source: Wisconsin Department of Natural Resources and SEWRPC

Large volumes of groundwater are now exported out of the Lake's watershed to the DelaHart wastewater treatment plant, effectively reducing the mass of groundwater-sourced minerals contributing to the Lake's alkalinity. This underscores the vital importance of maintaining, or better yet enhancing, the volume of groundwater entering Nagawicka Lake and its tributary streams.

Chlorophyll-a

Chlorophyll-*a* is the major photosynthetic ("green") pigment in algae. The amount of chlorophyll-*a* present in water is an indication of the biomass, or amount, of algae in the water. As presented in Table 2.12, chlorophyll-a concentrations above 10 μg/L tend to impair recreational activity. The median chlorophyll-*a* concentration for lakes in Southeastern Wisconsin is approximately 9.9 μg/L but can range from 1.8 to 706.1 μg/L.[75] Chlorophyll-*a* concentrations have been measured in Nagawicka Lake since the 1980s and indicate that chlorophyll-*a* levels are consistently well below the threshold of 10 ug/L associated with eutrophic conditions (Figure 2.34). Despite a few higher than typical values recorded in the 1990s, chlorophyll-*a* averages around 4.0 μg/L, a value significantly lower than the regional median. This indicates that algal blooms are generally not a problem and suggest moderately low phosphorus concentrations in Nagawicka Lake. Furthermore, since algal growth in the Lake is phosphorus limited, reducing phosphorus in the Lake will further reduce chlorophyll-*a* concentrations, yielding clearer water. The overall declining trend of chlorophyll-*a* concentrations may be the result of decreased phosphorus loading. Unfortunately, no comparative chlorophyll-*a* measurements are available for the period of time before treated wastewater was diverted from the Lake's watershed.

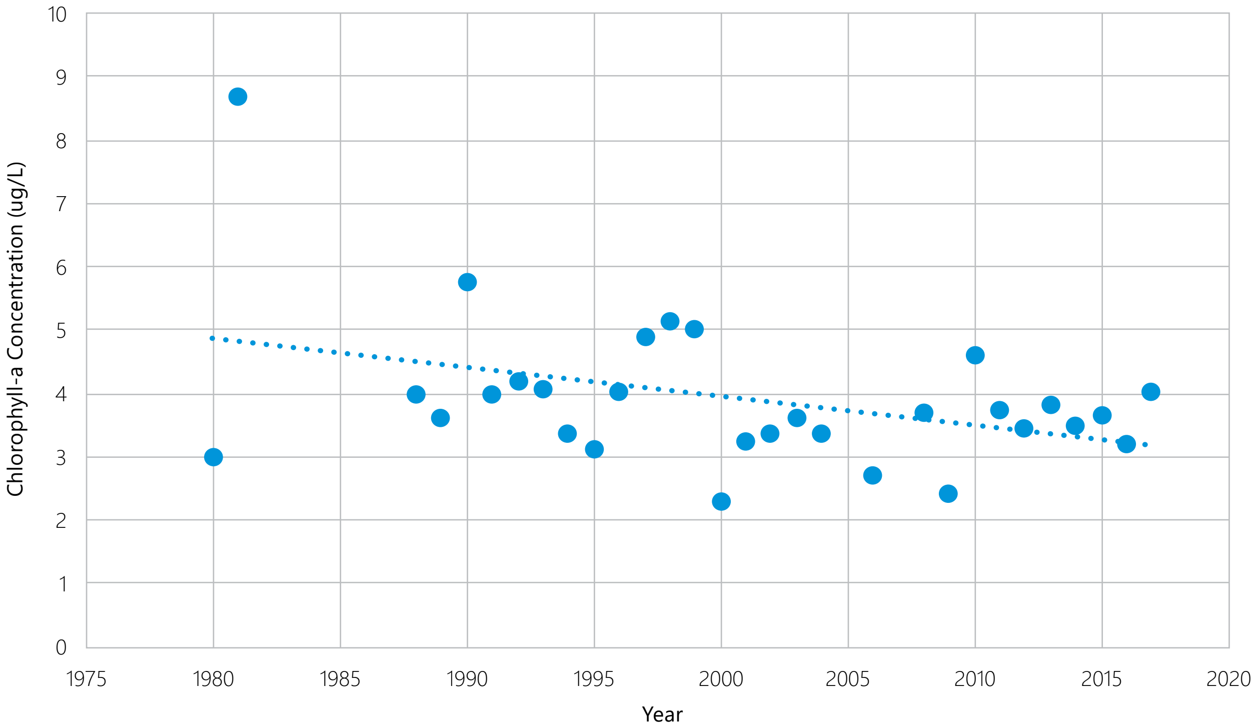
Cyanobacteria and Floating Algae

Algae is an important and healthy part of lake ecosystems. Algae is a foundational component of lake food chains and produces oxygen in the same way as rooted plants. Many kinds of algae exist, from single-cell, colonial, and filamentous algae to cyanobacteria (see Figure 2.35). Most algae strains are beneficial to lakes when present in moderate levels. However, the presence of toxic strains (see Figure 2.36), as well as excessive growth patterns, should be considered issues of concern. As with aquatic plants, algae grow faster in the presence of abundant phosphorus (particularly in stagnant areas). Consequently, when toxic or high volumes of algae begin to grow in a lake, it often is a sign of phosphorus enrichment or pollution.

Algae populations are quantified by abundance and composition. Suspended algal abundance is estimated by measuring the chlorophyll-*a* concentration in the water column. High concentrations are often associated

[75] *Wisconsin Department of Natural Resources Technical Bulletin No. 138*, op. cit.

Figure 2.34
Nagawicka Lake Average Chlorophyll-*a* Concentrations, 1980 – 2017



Source: SEWRPC

with green-colored water. Samples also can be examined to determine if the algae are toxic or nontoxic. As stated above, recent chlorophyll-*a* concentrations are well below eutrophic levels, suggesting few if any algal blooms. Recommendations for continuing water quality measurements such as chlorophyll-*a* are discussed in Chapter 3 of this report.

Trophic State

Trophic state index equations are used to convert summer water clarity, chlorophyll-*a*, and phosphorus concentration to a common measurement unit used to assess the overall productivity of a lake and allow lake-specific information to be compared and contrasted to other lakes.[76] TSI values based upon chlorophyll-*a* are considered the most reliable estimators of lake trophic status. During the past five years, chlorophyll-*a* values have been very consistent, generating an average TSI value of 45 (see Figure 2.37). This places Nagawicka Lake in the center of the range defining a lake as mesotrophic, and defines it as a two-story lake community exhibiting "good" condition.[77] Chlorophyll-*a* values have slowly declined throughout the period of available record, suggesting that the Lake is gradually returning to a condition more representative of its natural, less nutrient rich, state.[78] Secchi depth (water clarity) TSI values have also been declining for the entire period of record. This is logical since lower chlorophyll-a values generally correspond with clearer water.

Phosphorus TSI values were very high in the 1970s with values indicating eutrophic to hypereutrophic lake conditions and suggesting a high potential for algal blooms and undesirable lake health. Wastewater treatment plant effluent was diverted from the Lake in 1980. Unfortunately, no lake water phosphorus

[76] *R.A. Lillie, S. Graham, and P. Rasmussen,* Trophic State Index Equations and Regional Predictive Equations for Wisconsin Lakes, Research Management Findings, Number 35, *Bureau of Research – Wisconsin Department of Natural Resources, May 1993.*

[77] *WDNR, 2019,* op cit.

[78] *A 2004 WDNR study of diatoms in Nagawicka Lake's bottom sediment suggests that the Lake was an oligo-mesotrophic lake before European settlement. More information can be found in the full report: Garrison, 2004,* op. cit.

information is available for the period immediately after diversion. However, by the early 1990s, phosphorus TSI was commonly reduced to values within the mesotrophic category. Phosphorus TSI values have fluctuated over time, but most commonly indicate mesotrophic Lake conditions.

Throughout the period of record, phosphorus TSI values generally exceed both water clarity-based and chlorophyll-*a*-based TSI values. Furthermore, available data strongly suggests that phosphorus TSI values are slowly creeping higher, a situation contradicting the improving Lake conditions suggested by the chlorophyll-*a* and secchi depth TSIs. This situation causes the phosphorus-based TSI divergence to be increasingly prominent. This divergence is particularly pronounced since the year 2000 and could be related to the Lake's infestation with zebra mussels.[79] The mussels filter feed, removing algae and other particles from the water column, clearing the water, and producing higher than expected secchi values. At the same time, the mussels excrete phosphorus as part of their digestion process, potentially increasing lake water phosphorus concentrations. This slow rise in phosphorus TSI should be monitored, since phosphorus concentrations are the nutrient limiting algal growth in the lake. If the rise in phosphorus continues, undesirable and tangible changes to apparent Lake health could become apparent.

Chloride

Under natural conditions, surface water in Southeastern Wisconsin contains very little chloride. Historical data suggests that before extensive development, Southeastern Wisconsin lakes commonly contained water with less than 5 mg/L chloride. Most Wisconsin lakes saw little increase in chloride concentrations until the 1960s, but a rapid increase thereafter.[80] Chloride concentrations in Nagawicka Lake were first recorded from September 1973 to February 1975, at which time concentrations averaged 23.0 mg/L. Chloride concentrations were again recorded from April 1997 to April 2000. During that period chloride concentrations averaged 56.2 mg/L (Figure 2.38). The concentration of the most recent chloride sample analyzed from Nagawicka Lake in April of 2004 was 74.1 mg/L. Given what is observed in other lakes in the Region, and the trend of the available data, current values could be substantially higher (e.g. approaching or exceeding 100 mg/L).

Figure 2.35
Common Types of Non-Toxic Algae

Hydrodictyon

Spirogyra

Chlamydomonas

Source: (1) Lewis Lab (2) University of New Mexico (3) Taranaki Regional Council & Landcare Research

Chloride is considered a conservative pollutant, meaning that natural processes (other than evaporation) typically do not detain or remove it from water. Humans use chloride bearing materials for a multitude of purposes (e.g., road anti-icing and deicing, water softening, industrial processes). Therefore, chloride concentrations are normally positively correlated with human-derived pollutant concentrations. Chloride

[79] *Zebra mussels were verified to exist in Nagawicka Lake during 1998.*

[80] *Ibid.*

is indicative of a suite of human-sourced and human enriched chemicals. These chemicals include agricultural nutrients and pesticides, pharmaceuticals, petroleum products, and a host of other substances in common use by modern society. For this reason, chloride concentrations are a good indicator of the overall level of human activity, potential impact, and possibly the overall health of a water body. Increasing chloride concentrations suggest that Nagawicka Lake is subject to cultural pressure and the Lake has a propensity to accumulate human-introduced substances, a condition that could reduce water quality and overall ecosystem function over time. Some lakes in the Region have water containing well over 200 mg/L.

Although the Lake's most recently recorded chloride concentrations did not exceed regulatory guidelines and are not at the extreme range of local values (see Table 2.12), different plant and animal species have varying abilities to survive or thrive in saltier environments. For example, reed canary grass, a common invasive species of wetland and riparian settings, is well-adapted to salty water environments.[81] Similarly, Eurasian water milfoil can survive levels of industrial and salt pollution that eliminates native aquatic plants.[82] At least a few invasive animal species are also more tolerant of saltier water than native fish species. For example, invasive round goby (*Neogobius melanostomus*), a fish introduced from brackish water areas of Eurasia, grows better in higher salt environments and tolerates salt concentrations that are lethal to native fish species.[83] Therefore, progressively higher chloride concentration may increasingly favor undesirable changes to the flora and fauna of the Lake and its watershed.

Figure 2.36
Appearance of Toxic Algae Blooms

Microcystis

Cylindrospermopsis

Source: (1) National Oceanic and Atmospheric Administration
(2) St. John's River Water Management District

Chloride levels recorded in the surveyed section of the Bark River average 65.9 mg/L, with a median of 52.8 (Figure 2.39). The highest value recorded was a measurement of 438 mg/L near the Delafield-Hartland (DelaHart) Water Pollution Control Commission wastewater treatment plant in June of 1980. This was the only chloride measurement taken at that site and the concentration far exceeds any other chloride readings taken on this stretch of the River. However, it is likely that chloride concentrations exceed regulatory guidance during certain winter snow removal/snow melt events. Specific conductance information recently collected by the Commission staff from the nearby Pewaukee River revealed pronounced, short-term water conductivity spikes in winter. Elevated conductivity is related to the amount of salt in water, and clearly indicative of a situation suggesting elevated chloride concentrations related to road de-icing.

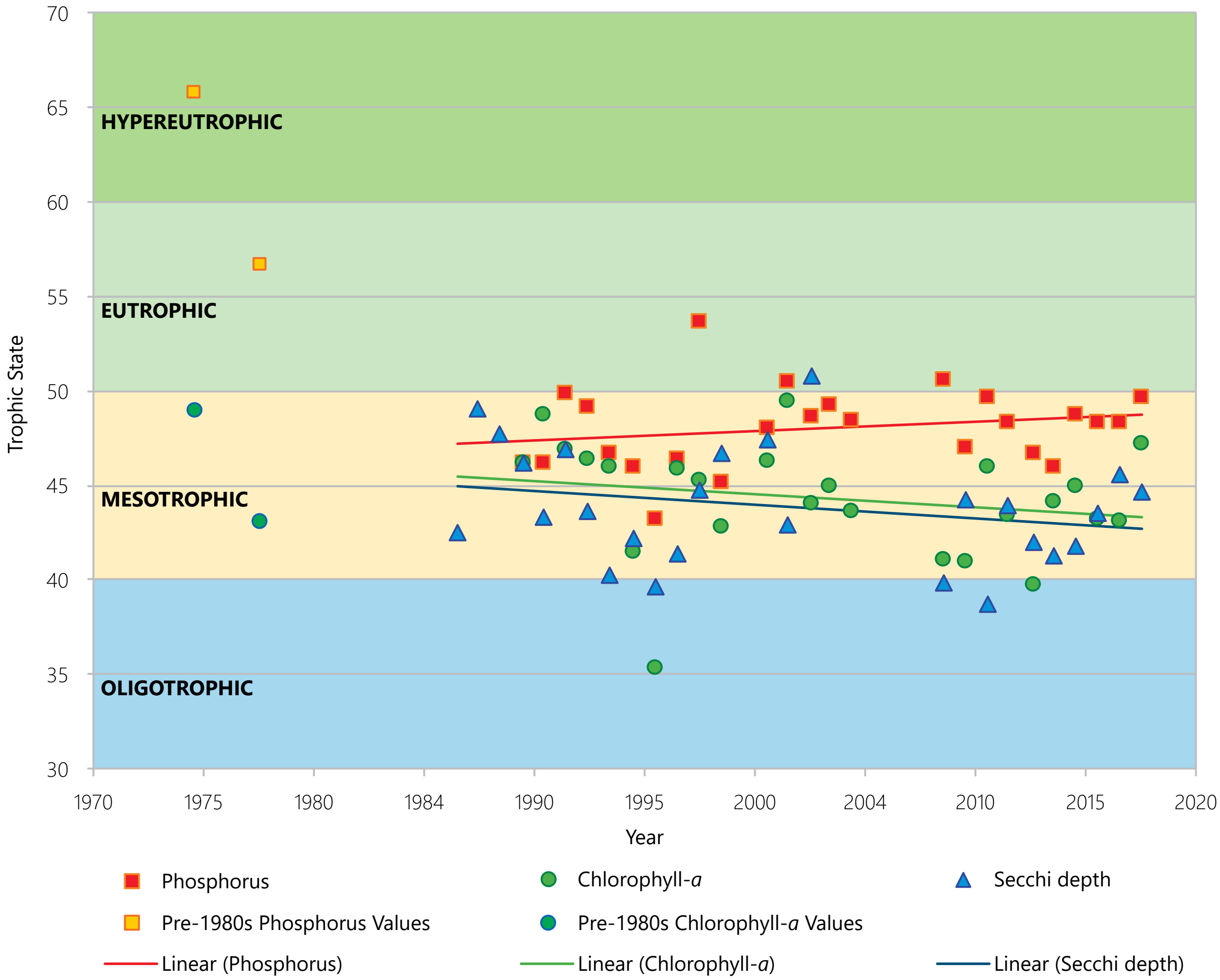
Management efforts to reduce chloride loading to Nagawicka Lake and other waterbodies throughout the Region are an important issue of concern. Winter road deicing practices are only one component of this issue. Periodic chloride concentration monitoring, coupled with regular field measurements of specific conductance, provides an excellent low-cost mechanism to monitor overall human influence on the Lake.

[81] *N. Prasser and J. Zedler, "Salt Tolerance of Invasive Phalaris arundinacea Exceeds That of Native* Carex Stricta *(Wisconsin),"* Ecological Restoration *28(3): 238-240, 2010.*

[82] *A.E. Schuyler, S. B. Anderson, and V. J. Kolaga, "Plant Zonation Changes in the Tidal Portion of the Delaware River,"* Proceedings of the Academy of Sciences of Philadelphia, *144: 263-266, 1993.*

[83] *S. Karsiotis, L. Pierce, J. Brown, and C. Stepien, "Salinity Tolerance of the Invasive Round Goby: Experimental Implications for Seawater Ballast Exchange and Spread to North American Estuaries,"* Journal of Great Lakes Research *38(1): 121-128, 2012.*

Figure 2.37
Average Summer Trophic Status Index Measurements for Nagawicka Lake: 1973 – 2017



Source: Wisconsin Department of Natural Resources and SEWRPC

Tributary Rivers and Streams

Water quality data has also been collected at several sites along the Bark River since the early 1970s. The sites along the stretch of the River surveyed by Commission staff in 2016 are identified on Map 2.22. Data collected as part of these initiatives is summarized in the following text.

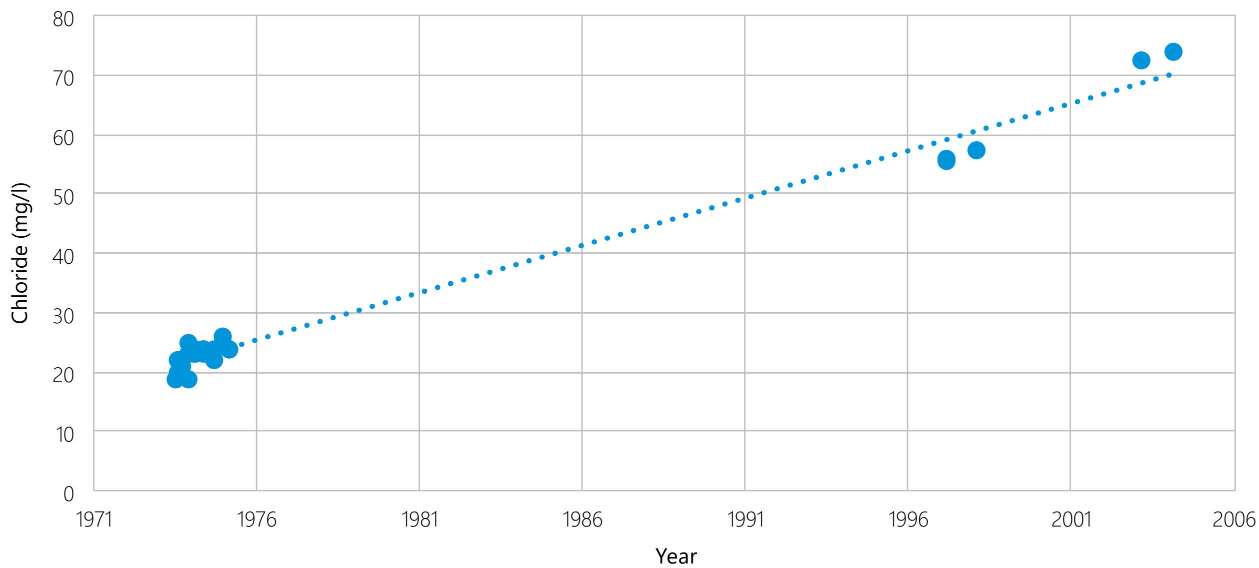
Temperature and Dissolved Oxygen

Water temperature has been monitored in several reaches of the Bark River for many years (see Figure 2.40). Over the nearly 20-year period of record, River water temperatures rarely exceed the upper seventy-degree range. These seasonal maximum values are at or slightly above the upper limit of the range desired to maintain healthy warmwater stream ecology.[84,85] Over time, it appears that the maximum annual water temperatures in the River have slightly declined, a situation favoring stream health. This may be related to increasing riparian vegetation. Unfortunately, the decline of ash has a particularly profound effect on riparian vegetative communities. Green ash (*Fraxinus pennsylvanica*) is especially common in wet soil areas such as those found along streams and lakes. Therefore, stream shading may decrease as ash fade from the

[84] *For cool-warm mainstem streams, maximum daily mean water temperature should remain at or below 72.6 to 76.3 degrees Fahrenheit.*

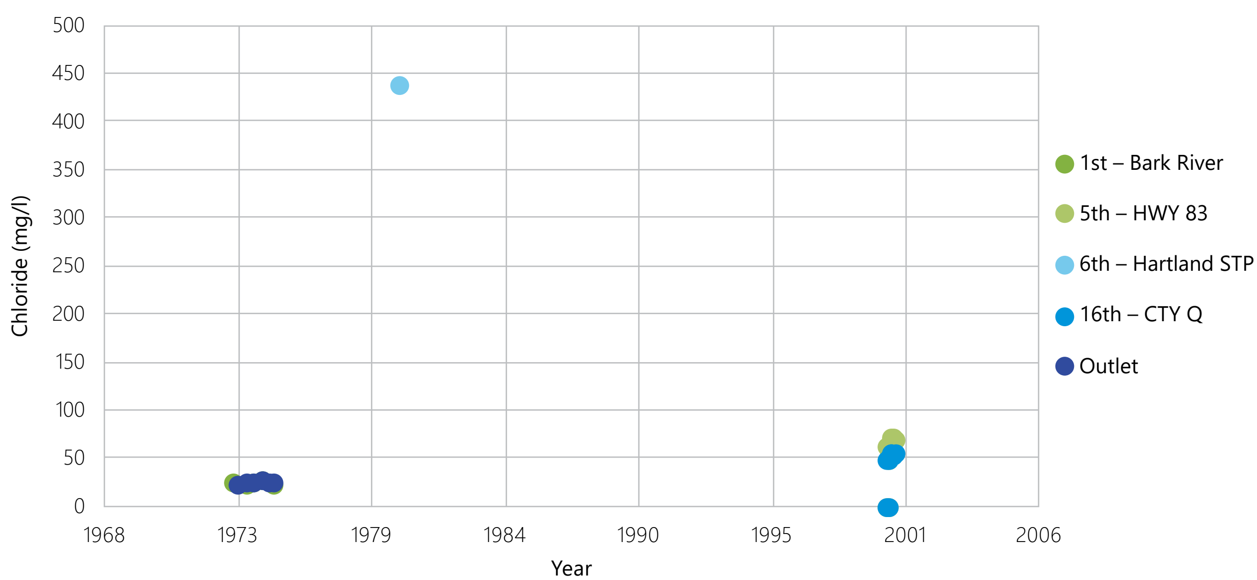
[85] *WDNR, 2019,* op. cit.

Figure 2.38
Chloride Concentrations, Nagawicka Lake: 1973 – 2004



Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.39
Average Chloride Concentrations in the Bark River



Source: Wisconsin Department of Natural Resources and SEWRPC

landscape, and temperatures may increase. Strategies that continue temperature monitoring and replace trees that shade the River are highly desirable.

Dissolved oxygen concentrations have been monitored at various locations along the Bark River for many years (see Figure 2.41). Oxygen concentrations in the River are consistently at or above levels required for stream health. The large variation in oxygen content found in river water is largely related to temperature—less oxygen is capable of dissolving into warm water. Therefore, low oxygen values are most common during summer months. Low oxygen values during other times of the year suggest heavy oxygen demand, a situation often related to excessive organic matter undergoing degradation. For example, the lowest oxygen value measured in the River occurred on November 13, 2004, a time of the year when large quantities of leaves enter and are degraded within water bodies. A few oxygen values suggest that the River experiences

Map 2.22
Bark River Monitoring Station Locations

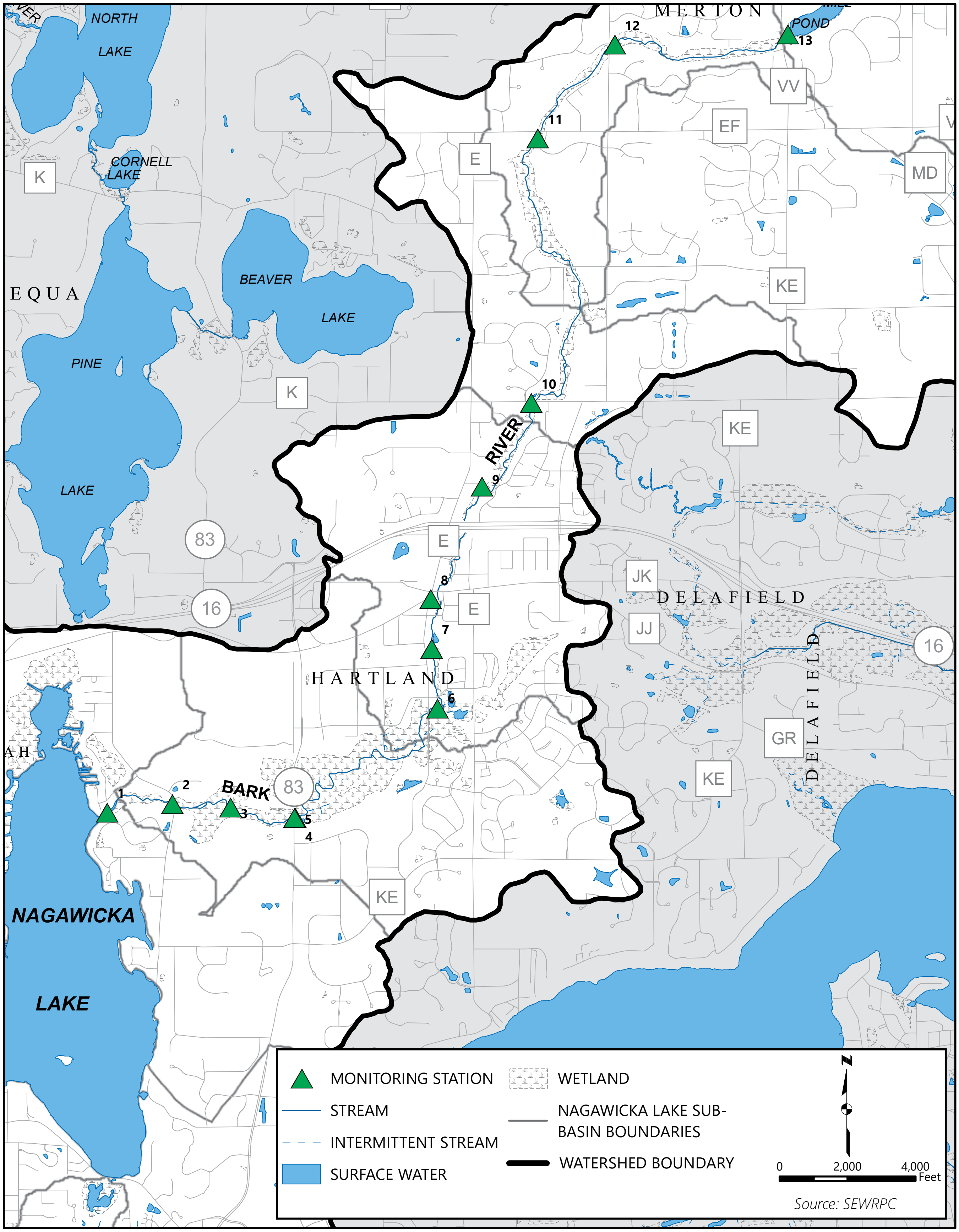
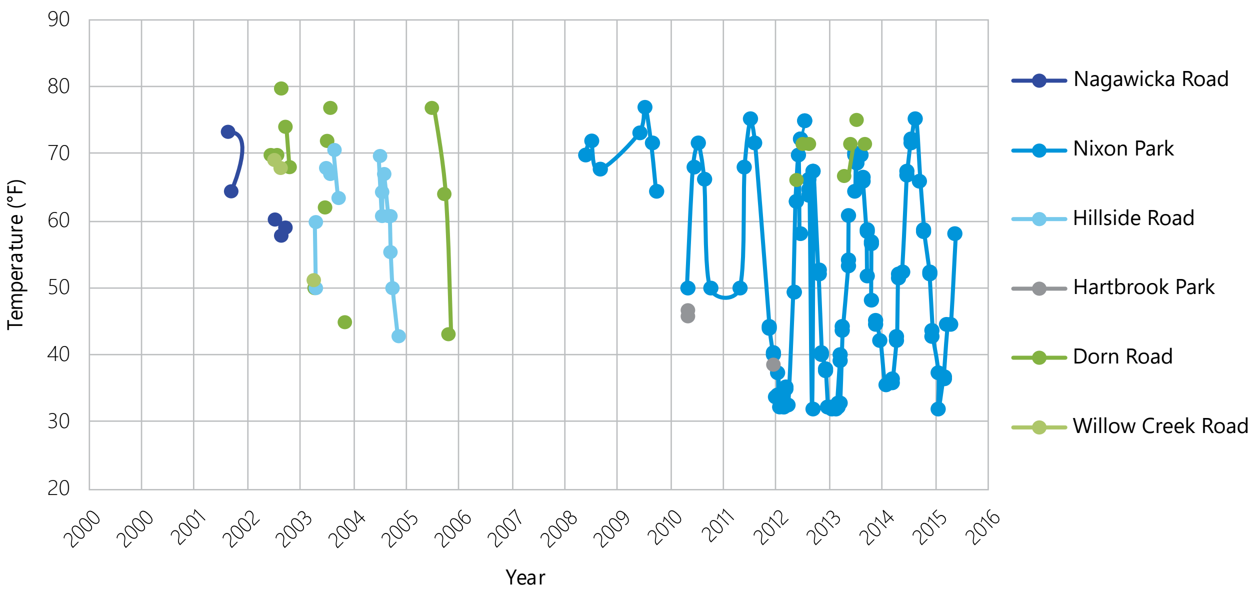


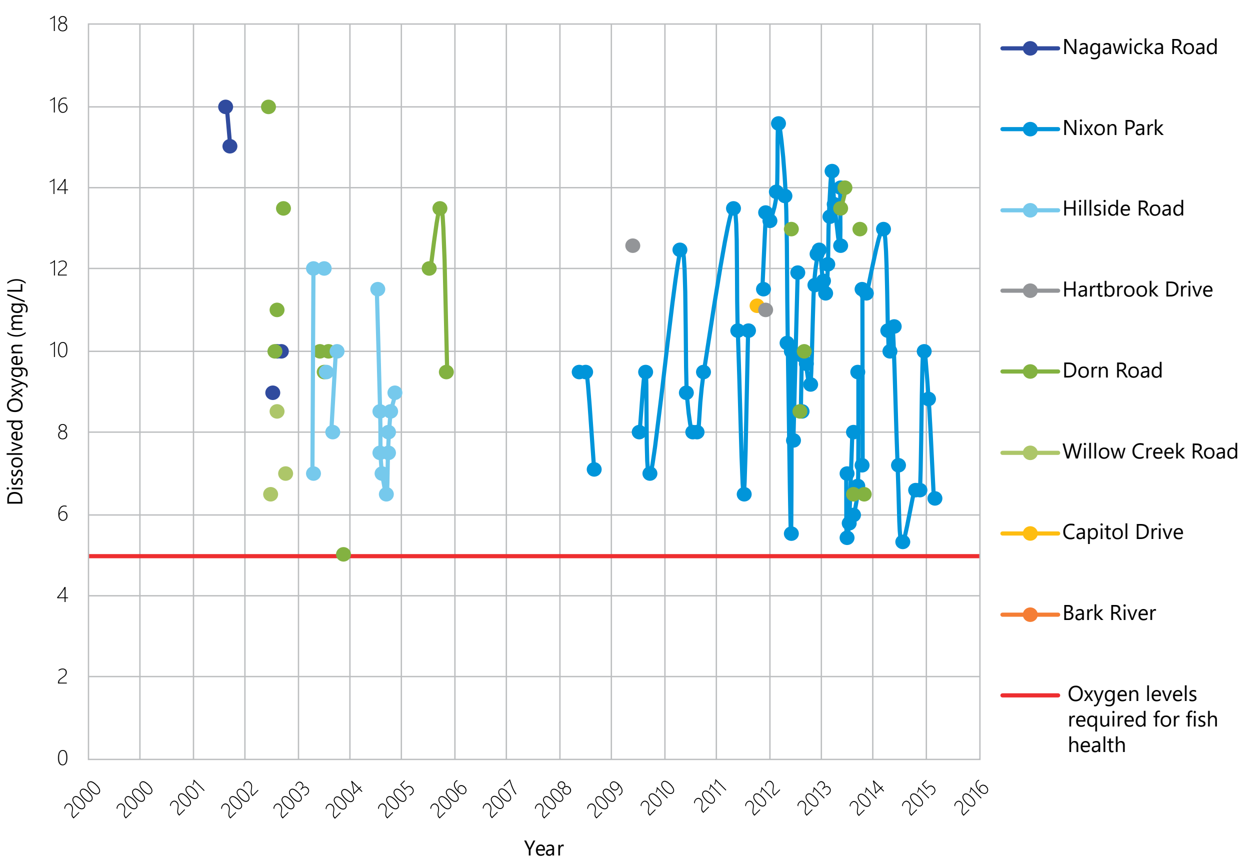
Figure 2.40
Water Temperatures at Bark River Monitoring Sites: 2000 – 2016



Note: Monitoring sites are in order from downstream to upstream.

Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.41
Dissolved Oxygen Concentrations in the Bark River



Source: Wisconsin Department of Natural Resources and SEWRPC

oxygen supersaturation at times, a condition injurious to aquatic life. Supersaturation is commonly related to eutrophic conditions and relatedly, abundant aquatic plant and algal growth.

Phosphorus

Phosphorus concentrations along the surveyed section of the Bark River average 0.11 mg/L, which exceeds the Chapter NR 102.06 0.075 mg/L phosphorus limit for streams and small rivers. Two monitoring sites, the 1st Site - Bark River site and the 4th site - Nagawicka Road, commonly exceeded this limit (Figure 2.42, Map 2.22). The Nagawicka Road site had both the highest and the lowest total phosphorus values in 2003, with a low of 0.02 mg/L in November and a high of 0.59 mg/L in May revealing large seasonal variation.

Transparency

Water clarity was measured in the Bark River with a turbidity tube. Most samples yielded turbidity readings of over 100 centimeters, suggesting that the section of the Bark River surveyed has excellent water clarity (see Figure 2.43). The site at Hillside Road had especially low turbidity readings, with all 14 readings reporting 120 centimeters of water clarity. Transparency levels increased at the monitoring site in Nixon Park, from an average of 68.5 cm in 2009 to an average of 86.0 cm in 2016.

Phosphorus and Sediment Loading and Deposition

Monitoring and reducing the loads of phosphorus and sediment to Nagawicka Lake is a major goal of this management plan, as load reduction will improve Lake water quality, reduce nutrient availability for algae and aquatic plants, and increase the effective lifespan of any dredging projects. The Commission used its own survey data, USGS monitoring data, and model output from several sources to estimate phosphorus and sediment loads to Nagawicka Lake as well as sediment accumulation within the Lake.

Phosphorus Loading

<u>Bark River</u>

The USGS monitored the mass of phosphorus transported by the Bark River a short distance upstream of its mouth in Nagawicka Lake for nearly four years. Trends in this data set can be evaluated and compared to the Bark River's flow in Figure 2.44. As can be seen from this data, the Bark River delivers comparatively little phosphorus (0.8 to 1.4 pounds per day) to the Lake during most days. To put this in perspective, one small bag of lawn starter contains nearly four pounds of phosphorus. However, the Bark River becomes a significant source of phosphorus to the Lake during periods of heavy runoff (see Figure 2.44). Phosphorus is tightly bound to soil particles. During periods of heavy runoff, soil is eroded, the River becomes turbid, and phosphorus transport rates greatly increase. Half of the total phosphorus load transported by the Bark River occurred during about 10 percent of the days during the monitoring period. On such days, the Bark River transports 14.5 to 109 pounds of phosphorus to the Lake per day.

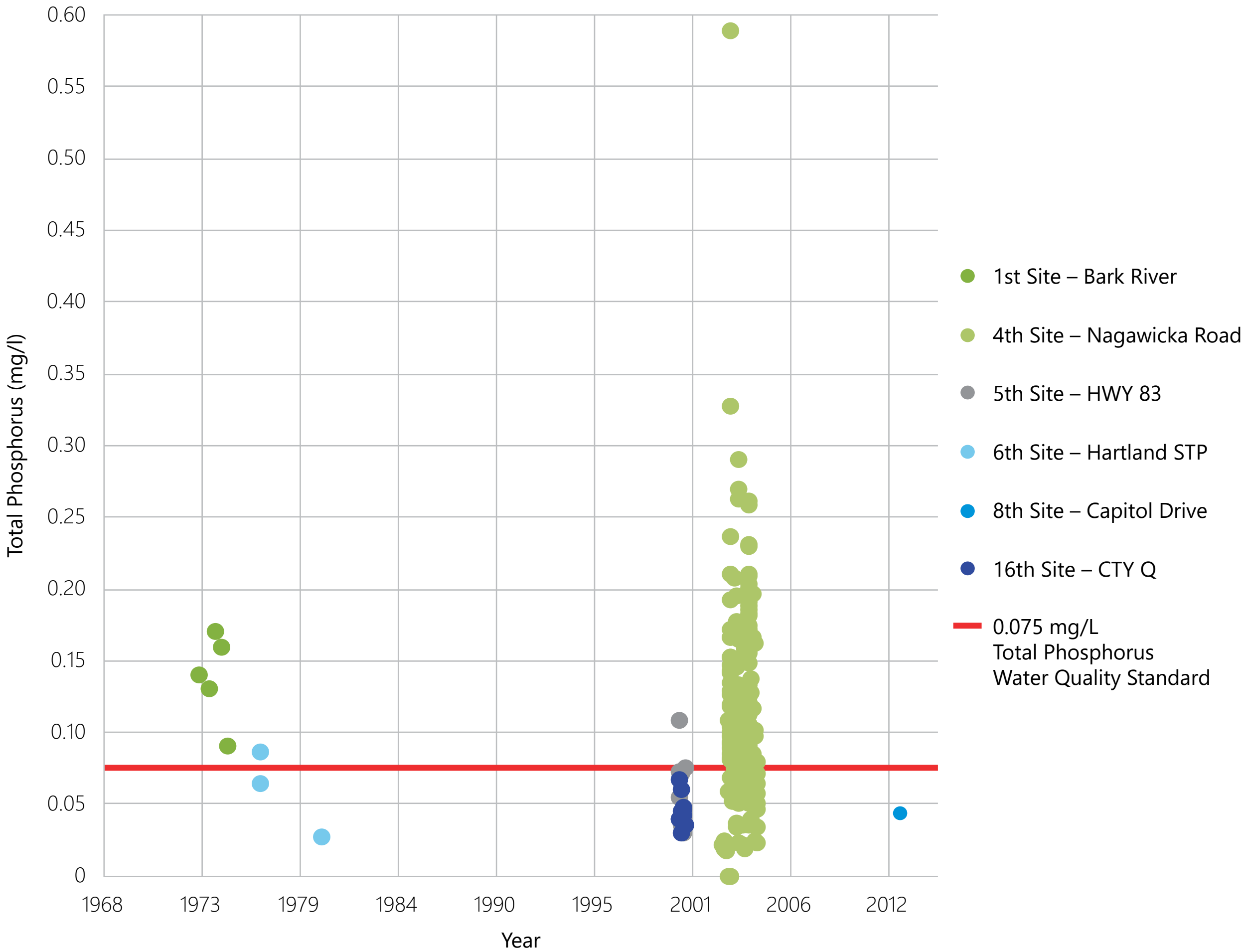
Most of the Bark River's total phosphorus load for the monitoring period occurred during well-defined multi-week time blocks. During such periods, precipitation, soil conditions, cropping practices, and other factors combined to cause greater erosion and transport of sediment and phosphorus to streams. For example, over 2,200 pounds of phosphorus (well over 20 percent of the total phosphorus transported by the Bark River during the entire 47-month study period) occurred over a 2-month period (mid-May to mid-July 2004). This equates to an average daily phosphorus transport value of over 36 pounds per day during the two-month period. Three or four other similar periods likely account for the majority of the phosphorus delivered to the Lake. These periods occurred during all seasons.

Based upon the available data, the Bark River has a 50 percent chance of delivering equal to or less than 3.5 pounds of phosphorus per day. The River's daily phosphorus load has a 5 percent chance of being less than 1 pound, and a 5 percent chance of being greater than 26.5 pounds on any given day. Given that the watershed upstream of the point of measurement covers 22,976 acres, the median annual phosphorus yield for the Upper Bark River is about 0.056 pounds per acre (Table 2.15).

<u>Lake-Direct Watershed Phosphorus Loading</u>

The USGS collected samples to quantify phosphorus contributed by the Lake-direct drainage watersheds, values that can be used to contrast phosphorus yield of the Unit Area Load (UAL) and Wisconsin Lake Model Suite (WiLMS) models discussed later in this section. This study sampled individual subwatersheds

Figure 2.42
Total Phosphorus in the Bark River: 1973 – 2012

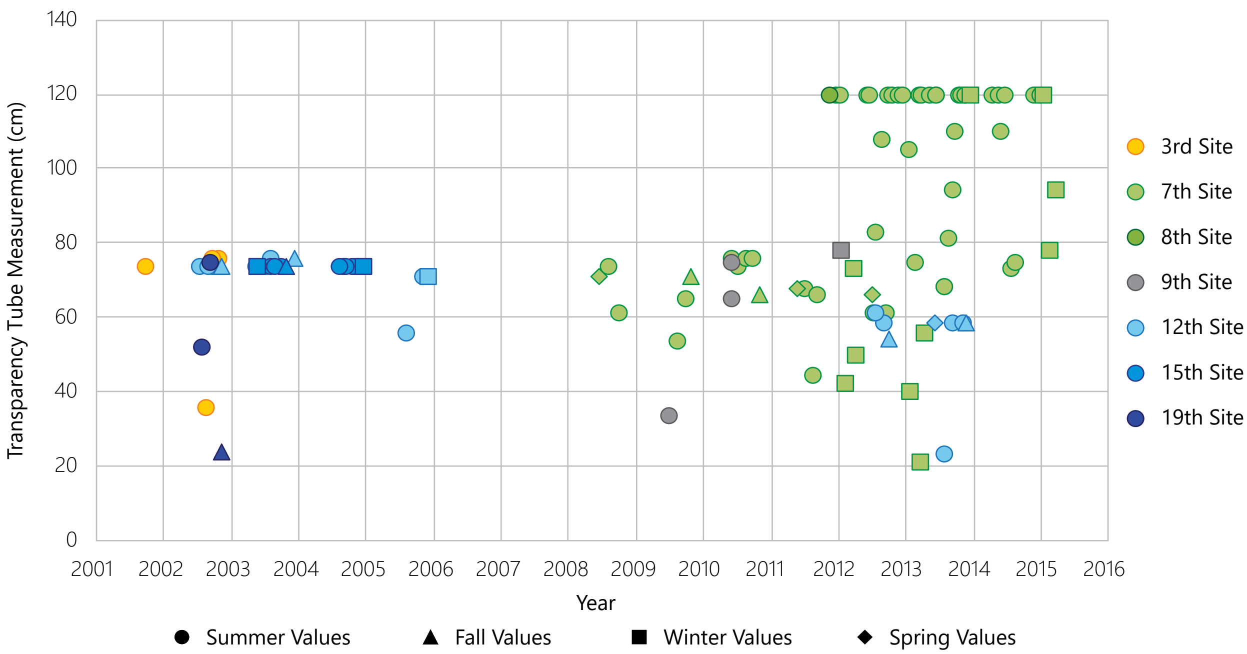


Source: Wisconsin Department of Natural Resources and SEWRPC

around Nagawicka Lake to evaluate differences between watersheds with direct-drainage to the Lake and the Bark River watershed upstream of the Lake. As the USGS measured phosphorus concentrations at the inlet monitoring site on the Lake, the study was unable to differentiate between the phosphorus loading of sub-basins within these watersheds. The highly developed areas in sub-basins 7, 8, 10, and 11 yield roughly four to five times more phosphorus per acre than the comparatively rural areas of the Bark River watershed upstream of the Lake (sub-basins 1 through 6) (see Table 2.15).[86] The high phosphorus loading per acre of in Lake-direct drainage areas, coupled with their close proximity to the Lake, make them especially attractive for active management to reduce phosphorus inputs to the Lake and the Bark River. The relatively undeveloped area to the southwest of the Lake (sub-basin 9) yielded the least phosphorus per acre of all the Lake direct drainage sub-basins.

[86] *The Bark River load estimates include urbanized areas in communities such as the Villages of Hartland and Merton. These upstream urbanized areas probably exhibit phosphorus loading rates similar to the urbanized Lake-direct drainage watersheds, but, unlike the Lake-direct watersheds, the proportion of the urbanized land in the Bark River watershed is comparatively small. Nevertheless, urbanized portions of the Bark River watershed likely contribute a significant fraction of the total phosphorus load carried by the Bark River to Nagawicka Lake.*

Figure 2.43
Transparency of the Bark River



Source: Wisconsin Department of Natural Resources and SEWRPC

Sediment Loading

As part of the natural aging process, lake basins gradually fill with sediment. This sediment is primarily derived from the following processes.

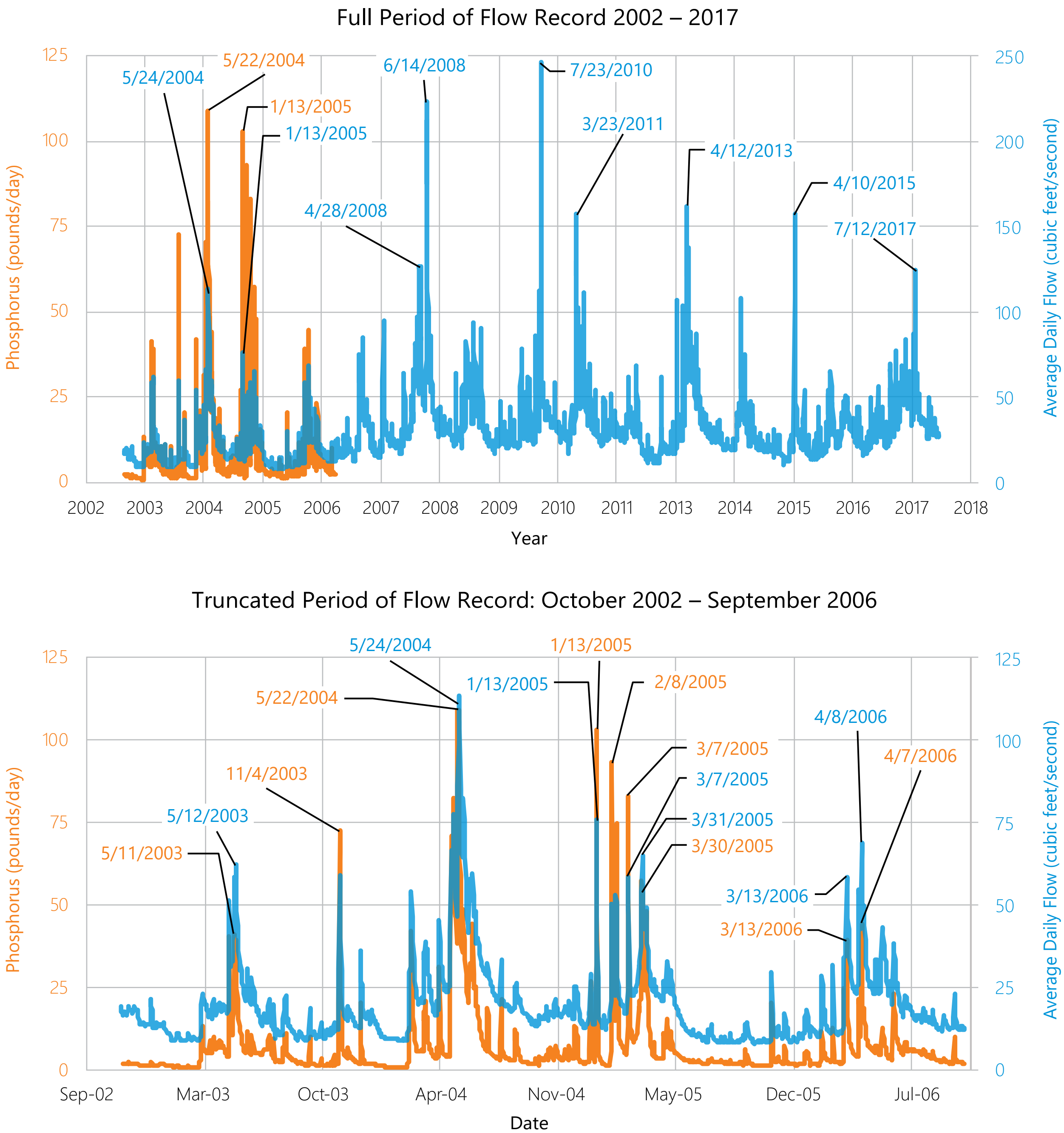
- **Sediment carried to a lake by actively flowing water.** Erosion over broad expanses of upland areas is typically the primary source of such sediment to most lakes. This sediment is generally funneled to lakes through tributary streams. In some cases, general overland flow around the lake and shoreline erosion can also be significant contributors to a lake's overall sediment load. Much of the sediment carried to lake basins by moving water is comprised of inorganic gravel, sand, silt, and clay. Lakes with large watersheds, significant land and shoreline disturbance, and large expanses of quiescent water can accumulate large amounts of sediment each year. Coarser-grained sediments (i.e., silt, sand, and gravel) commonly accumulate near the point where moving water enters a lake. In contrast, portions of lakes well offshore or otherwise distant from moving water accumulate clay-size sediment. The actual amount of sediment entering lake basins is highly dependent on lake- and watershed-specific factors and is therefore highly variable.

  Lake sediment loads are most often estimated using models. If quantitative sediment information exists, it often is based upon sporadic sampling and may not adequately represent overall sediment load since the amount of sediment carried by flowing waters is highly dependent on flow conditions, seasons, and other factors. Furthermore, in most cases, samples quantify only suspended sediment load. Rivers and streams also transport sediment as bedload. Bedload is sediment that is too heavy for flowing water to suspend and instead it rolls, hops, or otherwise moves at or near the streambed in response to flowing water. Very few studies quantify bedload. However, studies in Wisconsin and nearby states generally suggest that bedload commonly transports a mass of sediment equal to between 25 percent and 400 percent of the mass transported as suspended load.[87,88] Therefore, if lake managers are interested in the *total* mass of sediment transported by flowing water to lakes, bedload must be considered.

[87] *M.D. Ladewig,* Sediment Transport Rates in the Lower Muskegon River and Tributaries, *Master of Science Thesis: Department of Natural Resources and Environment, University of Michigan, 2006.*

[88] *G.P. Williams and David L. Rosgen,* Measured Total Sediment Loads (Suspended Loads and Bedloads) for 93 United States Streams, *United States Geological Survey Open-File Report 89-67, 1989.*

Figure 2.44
Pounds of Phosphorus Per Day and Average Daily Flow of the Bark River (USGS 05426067 Bark River at Nagawicka Road in Delafield, WI) at the Inlet to Nagawicka Lake: 2002-2017



Source: U.S. Geological Survey and SEWRPC

- **Sediment carried to lakes by wind.** The atmosphere deposits significant amounts of sediment to lakes. Southeastern Wisconsin lakes commonly receive nearly 200 pounds of sediment per acre per year from atmospheric fallout each year.

- **Sediment formed by geochemical processes within a lake.** In most Southeastern Wisconsin lakes, groundwater entering the lake is "hard" and therefore rich in dissolved carbonate minerals. Some carbonate minerals may come out of solution once in a lake, a process promoted by biochemical processes associated with photosynthesis. The carbonate minerals precipitated from lake water often co-precipitate phosphorus, and the mixture of carbonate and phosphate minerals that settles to the

Table 2.15
Nagawicka Lake Watershed Phosphorus Yield Estimates: 2002 – 2004

Sub-Watersheds		**Annualized Phosphorus Areal Mass Flux (pounds/acre/year)**			
			Daily Values (November 1, 2002 to September 29. 2006)[a]		
Description	Corresponding Sub-Basin Number(s) in Current Study	Annual Average Values (November 1, 2002 to October 31, 2004)	Equaled or exceeded 10 percent of the time	Equaled or exceeded 50 percent of the time (median)	Equaled or exceeded 90 percent of the time
Bark River Upstream of Nagawicka Lake	1, 2, 3, 4, 5, and 6	0.12[a]	0.23	0.056	3.0
Largely Commercial Urbanizing Lake-Direct Drainage Area Southeast of Nagawicka Lake	8	0.46[a]	--	--	--
Largely Rural Lake-Direct Drainage Area Southwest of Nagawicka Lake	9	0.078[a]	--	--	--
Largely Low Density Residential Urbanized Lake-Direct Drainage Area Ringing Most of Nagawicka Lake	7, 10, and 11	0.57[b]	--	--	--

[a] *Values derived from laboratory analysis of water samples.*

[b] *Values derived from calibrated SLAMM model.*

Source: U.S. Geological Survey

lake bottom is often termed "marl". Marl deposits are common in Southeastern Wisconsin lakes that receive abundant groundwater discharge. The amount of marl deposited in lakes is extremely variable.

- **Sediment originating in a lake comprised of dead plants and animals.** All aquatic plants, algae, diatoms, fish, and other aquatic life eventually die and settle to the lake bottom. When the supply of such material exceeds the ability for material to be decomposed and removed from the lake bottom, organic deposits form. These deposits are commonly termed muck or peat. Muck is deposited throughout lake basins while peat is general confined to riparian wetlands. The amount of these materials deposited within lakes is highly variable and is highly dependent upon the level of lake nutrient enrichment.

Near-Shore Sediment Depth and Composition

Commission staff measured sediment depth throughout the nearshore areas of the Lake during 1999, 2000, and 2016. The results of the 1999 and 2000 surveys were combined and mapped (see Map 2.23). Sediment depths recorded during the 2016 survey are illustrated on Map 2.24. These measurements are inexact due to variations in methodology, but they do demonstrate the effectiveness of dredging projects undertaken throughout the Lake (Map 2.25).

Nearshore sediment composition was estimated during the 2016 aquatic plant survey. Of the 631 points surveyed, 52 percent were muck or flocculent sediment, 45 percent were sand or firm sediment, and 3 percent were rock or gravel. The results of this survey are presented in Figure 2.45.

Sediment Loads and Fate

A study of Nagawicka Lake's bottom sediment concluded that prior to European settlement, approximately 1,300 tons of sediment were deposited in the Lake each year. Following settlement, sedimentation rates increased through the late 1970s. The study suggests that Nagawicka Lake has one of the higher post-settlement sedimentation rates in Wisconsin, with an average sedimentation rate of 6,000 tons per year over the past 150 years. Between the early 1980s and early 2000s, sedimentation rates stabilized, averaging approximately 5,600 tons per year, a value over four times higher than natural conditions.[89,90] Assuming current sedimentation rates are 5,600 tons per year, and using the proportion of substances found in Lake-bottom sediment, approximately one-third of this sediment (roughly 1,800 tons) is attributable to in-Lake geochemical processes, one-tenth (roughly 600 tons) is attributable to accumulating organic matter, and the remainder (roughly 3,200 tons) is related to mineral soils deposited in the Lake from external sources.

Other approaches can be used to estimate Lake sedimentation rates. Using multiple methods to evaluate lake sedimentation helps determine if results are reasonable. One approach uses the USGS 2003-2004 phosphorus mass balance estimates and the typical phosphorus content of lake sediments (0.1 percent) to estimate the mass of sediment retained in the Lake each year.[91] Using these values, an average of over 2,100 tons of externally sourced sediment were deposited in Nagawicka Lake during the 2003-2004 time period, a value that is in the same general range as the 3,200 ton per year estimate derived from sediment core analyses described in the preceding paragraph.[92] As discussed in more detail in a subsequent section, the 2003-2004 time period was drier than normal. Drier conditions would depress phosphorus and sediment loads, a situation possibly explaining the lower value suggested by this analysis.

Another way to evaluate sediment delivered to the Lake considers quantitative data collected in the watershed and Region. Using available data, the magnitude of several of the discrete sediment loads to the Lake can be individually estimated.

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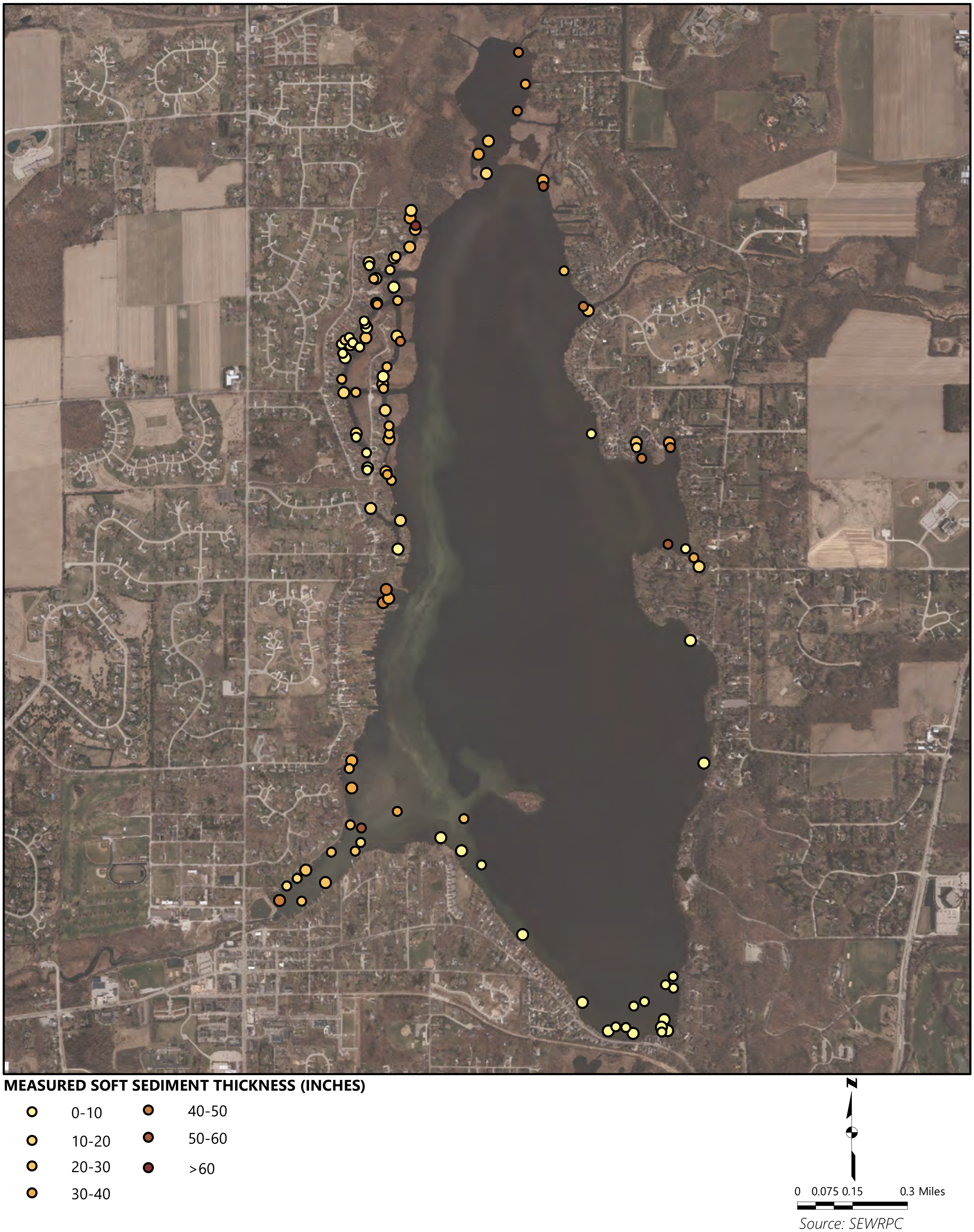
[89] *Garrison, 2004,* op. cit.

[90] *Sediment density varies with age, depth of burial, composition, and other factors. For this reason, sedimentation rates are commonly expressed in tons per year. Freshly deposited lake sediment commonly has a density of roughly 60 pounds per cubic foot. Therefore, one ton of freshly deposited lake sediment would occupy roughly 1-¼ cubic yards of space.*

[91] *I. Bojakowska, "Phosphorus in Lake Sediments of Poland – Results of Monitoring and Research,"* Limnological Review *16, 2016.*

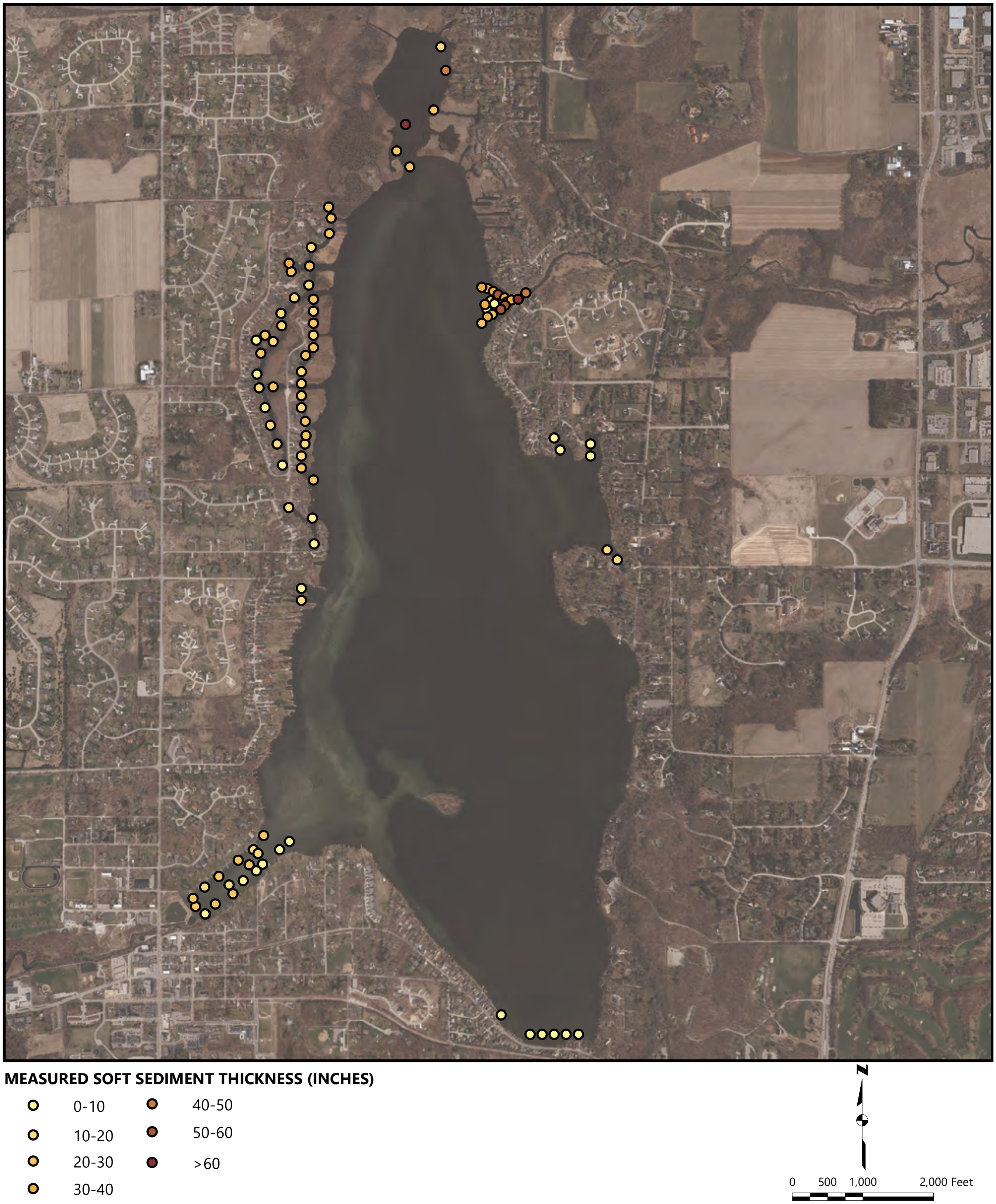
[92] *Samples of actual Lake bottom sediment phosphorus content would be needed to refine this estimate. Therefore, this value is suggested to be used only to corroborate the values determined by the sediment core study.*

Map 2.23
Measured Nagawicka Lake Soft Sediment Thickness: 1999/2000



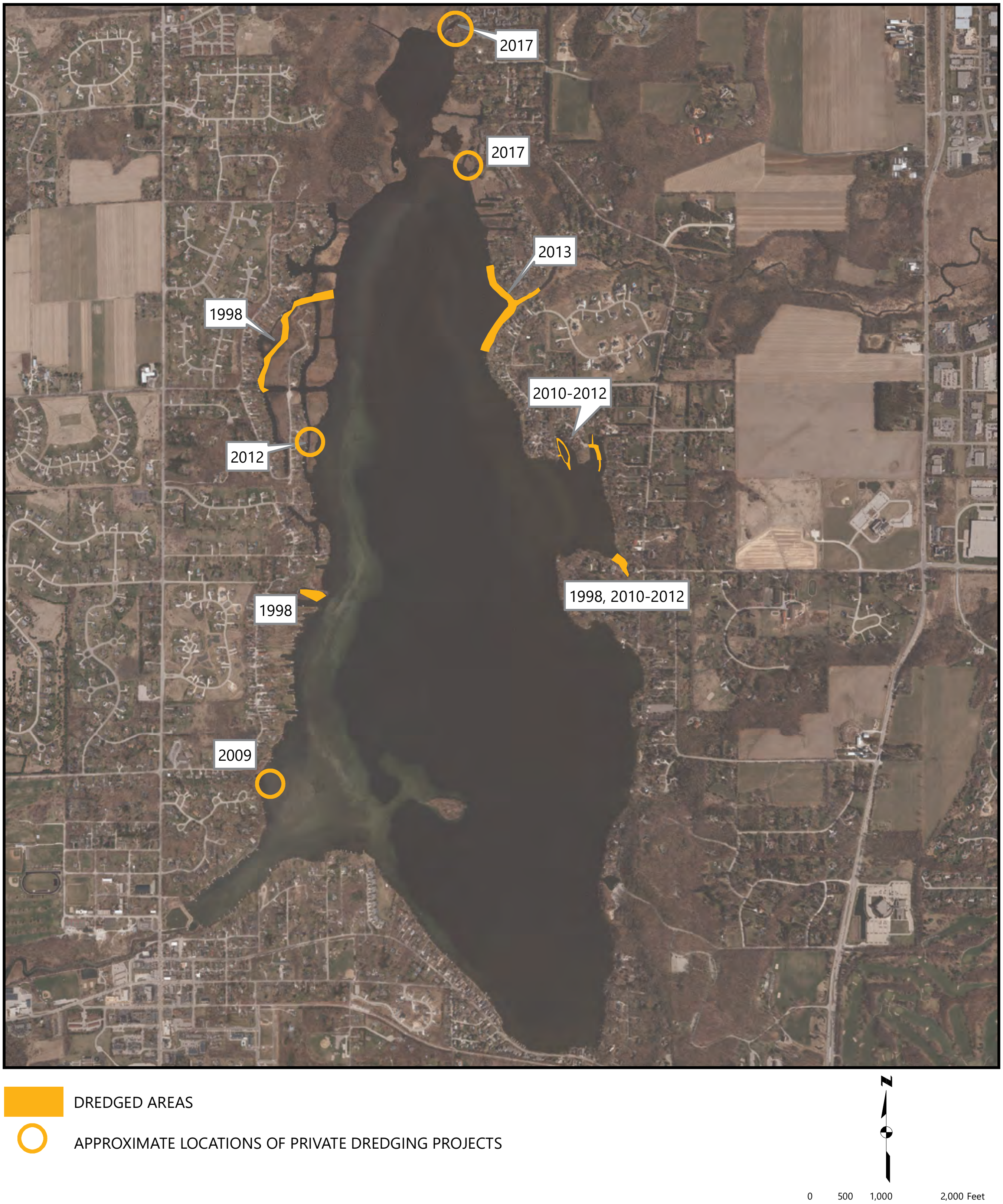
Source: SEWRPC

Map 2.24
Measured Nagawicka Lake Soft Sediment Thickness: 2016



Source: SEWRPC

Map 2.25
Portions of Nagawicka Lake Dredged: 1998 – 2017



Source: Lake Welfare Committee and SEWRPC

Figure 2.45
Sediment Composition in Nagawicka Lake

Source: SEWRPC

- **The Upper Bark River,** by far the largest tributary to Nagawicka Lake and covers 23,534 acres in sub-basins 1, 2, 3, 4, 5, and 6 (see Map 2.10). The Bark River is the largest single contributor of externally sourced sediment to the Lake. Much of this sediment would tend to accumulate as a delta at the point where the flowing waters of the River enter the quiescent waters of the Lake.

  Between 2002 and 2004, the USGS measured daily suspended sediment loads in the Bark River a short distance upstream of the Lake. During this time period, the Bark River delivered on average approximately 1,000 tons of suspended sediment per year. The 2002-2004 studied confirmed that most suspended sediment was delivered in short discrete pulses when the River's flow was high, punctuated by comparatively long time periods where the River is relatively low and transports little sediment. This conclusion may be illustrated by the fact that over two-thirds of the suspended sediment delivered by the River occurred over less than 5 months of the entire 24-month period of record. Moreover, while the average River suspended sediment load is slightly less than 3 tons per day, less than 1.3 tons of suspended sediment were delivered to the Lake during more than 50 percent of the study period days.

  The 2002 to 2004 time period over which suspended sediment loads were measured does not appear to have represented typical flows in the Bark River. Fortunately, the USGS has continued to measure the flow of the Bark River. During the two-year 2002 and 2004 study period, average monthly flow of the Bark River was roughly one-third less than measured during the 16-year period between 2002 and 2018. Since River flow and suspended sediment load are positively correlated, river flow and suspended sediment load were compared and a polynomial formula was used to predict suspended sediment load from flow data. The formula produced a coefficient of determination (r^2) value of 0.93, suggesting it predicts values well. Unfortunately, the 2002 to 2004 time period contain few large flow events, making validation of the formula's ability to estimate suspended sediment loads at high flow events less robust. Nevertheless, using this formula and average monthly flows recorded between November 2002 and September 2018 suggests that the Bark River delivers roughly 2,100 tons of suspended sediment to the Lake each year.

  Suspended sediment values quantify the mass of smaller size particles carried in the water column by the River but do not include the mass of larger particles that flowing river water moves near the riverbed (bedload). Heavier bedload particles are prone to settle to the Lake bottom immediately where the River enters the Lake. Lake property owners near the mouth of the Bark River are particularly interested in this issue, and dredging has taken place in this area to improve navigation.

  To judge the longevity of dredging initiatives, the LWC asked the Commission to estimate the total sediment load likely to be deposited in the Bark River delta area. This requires evaluation of total sediment load (suspended load and bedload). The Commission used regional suspended load/ bedload estimates to estimate the mass of bedload transported to the Lake each year.[93] Following this approach, the River's bedload sediment transport component is believed to deliver roughly 1,300 tons of sediment to the Lake each year. Therefore, the Bark River likely delivers a total of 3,400 tons of sediment to the Lake each year. Other studies in the Region report that the upper 20 inches of lake sediment deposited in delta type environments exhibit bulk densities ranging from 54 to 86 pounds per cubic foot.[94] Applying an average value of 70 pounds per cubic foot, the 3,400 tons of sediment deposited by the Bark River in Nagawicka Lake likely equals roughly 3,600 cubic yards of in-place sediment.

- **The Lake-direct watershed**, while much smaller than the Bark River watershed, is in overall terms much more urbanized. The Lake-direct watershed includes four urbanized sub-basins (7, 8, 10, and 11) and one largely rural sub-basin (9, see Map 2.10). Based upon phosphorus loads determined as part of the USGS study, the urbanized Lake-direct watershed likely delivers two-thirds the

[93] *Consulting regional studies and considering the morphology of the River and its watershed, the Bark River's bedload mass was believed to range from 25 to 100 percent of its suspended load. For the purpose of this study's computation, we used a value in the middle of this range (62 percent).*

[94] *Berrini & Associates, LLC,* An Assessment of the Mound Road Ponds to Determine Optimum Maintenance and Enhancement Options for Implementation*, June 2017.*

amount of suspended sediment to the Lake when compared to the entire Bark River watershed.[95] Furthermore, information collected by the USGS suggests that the largely residential Lake-direct drainage sub-basins ringing the Lake (sub-basins 7, 10, and 11) contribute significantly more sediment than the comparatively small, urbanizing, commercial land use sub-basin located to the southeast of the Lake (sub-basins and 8).

Based upon 2002 through 2018 flow information, typical sediment phosphorus content, and the flow/sediment relationship developed for the Bark River, that the largely urbanized residential sub-basins located west of the Lake (sub-basins 7, 10, and 11) may contribute an average of 1,800 tons (1,900 cubic yards) of sediment per year, while much smaller, semi-urbanized, largely commercial Lake-direct sub-basins to the southeast of the Lake (sub-basin 8) contributes roughly 440 tons (470 cubic yards) of sediment to the Lake each year. The non-urbanized lake direct sub-basin is likely a comparatively minor source of sediment to the Lake. Information collected by the USGS suggests that this watershed contributes roughly 140 tons (150 cubic yards) of sediment to the Lake each year. The relative contribution from these sources are compared in Figure 2.46.

- **Atmospheric sediment deposition** can be estimated from regional averages. Approximately 95 tons (roughly 100 in-place cubic yards) of sediment are deposited into the Lake per year from the atmosphere.

Adding these three sources suggests that almost 5,900 tons (over 6,200 cubic yards) of externally sourced sediment settles to the Lake bottom each year. This total does not include shoreline erosion which can contribute significant amounts of sediment to lakes in some circumstances. These totals also do not include internally sourced sediment loads such as precipitation of marl and organic debris.

Deposition Rate Estimates

To help the LWC consider the volume of sediment that may accumulate in various portions of the Lake, the Commission assumed that all bedload and half the suspended load was deposited on the Lake bottom near the point where flowing water enters the Lake. The other half of the suspended load and all atmospheric deposition was assumed to be deposited in the remainder of the Lake, with most deposition occurring in quiescent offshore waters. Using these assumptions, an average of roughly 2,500 cubic yards of sediment can be expected to be deposited near the mouth of the Bark River each year, 2,000 cubic yards can be expected to be deposited in deeper waters throughout the Lake, with the rest deposited in numerous smaller nearshore deposits (see Figure 2.47).

Simulated Phosphorus and Sediment Loads

Different land uses can contribute different types of pollution to a lake. While it is normal for some sediment and nutrients to enter a lake from the surrounding lands (a factor contributing to the natural lake aging process), when human activity contribute excessive quantities of sediment and nutrients and/or pollutants (such as heavy metals, chemical fertilizers, and oils) which would not have otherwise entered the system, these sources become an issue of concern. For example, sediment and nutrient loads greatly increase when land is disturbed through intensive tilling and construction, both which loosen soil allowing it to from source area and eventually enter streams and lakes.

To estimate the amount of non-point source pollutants entering the lake over time, presettlement (circa 1830s), historical (1963), current (2010), and planned watershed-wide land use information was assembled for each year of interest. Information was further quantified by watershed sub-basin. Land use data were used to drive two separate but similar non-point source pollutant loading models.[96]

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[95] *Phosphorus concentrations are typically directly linked to sediment concentrations; therefore the inverse can be used to approximate suspended sediment loads from phosphorus concentrations.*

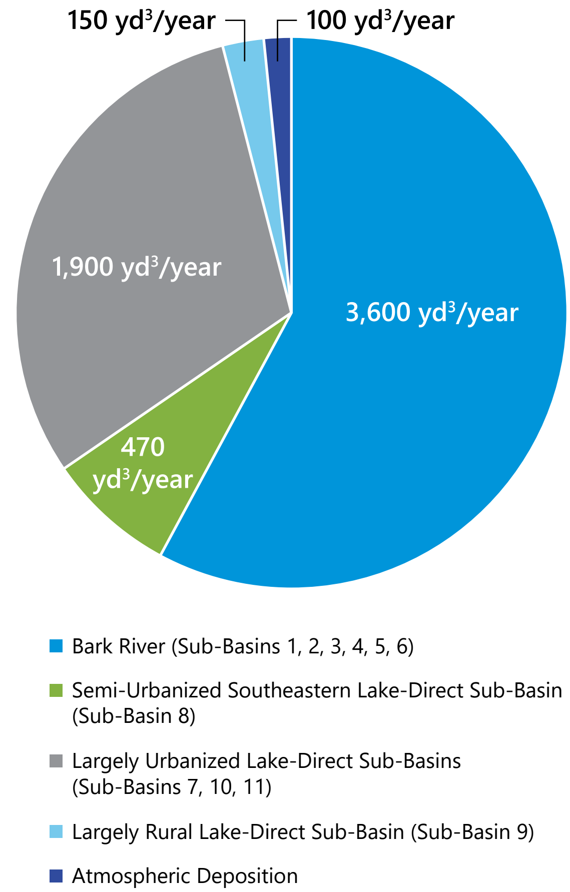
[96] *In this study, non-point source phosphorus, suspended solids, and urban-derived metal inputs to Nagawicka were estimated using the Wisconsin Lake Model Spreadsheet (WiLMS version 3.3.18) and/or the unit area load-based (UAL) model developed for use within the Southeastern Wisconsin Region. These two models operate on the general principal that a given land use will produce a typical mass of pollutants on an annual basis.*

The Commission's unit area load (UAL) model was used to simulate past, present, and near-term future Lake pollutant loads. Simulated parameters include sediment, phosphorus, copper, and zinc,[97] Predicted pollutant loads at each time step are segregated by land use as summarized in Table 2.16. These calculations assume that urban land use is the only significant source of heavy metals, and that atmospheric deposition has and will not change over time. Heavy metals monitoring has not occurred within the Lake. However, urban areas should be targeted if heavy metals become an issue within the Lake in the future.

Compared to pre-settlement conditions, significantly more sediment, nutrients, and other pollutants now reach Nagawicka Lake, a situation fostered by conversion of forest and grasslands to agricultural and urban land uses. Compared to presettlement conditions, Nagawicka Lake's phosphorus loads are about nine times greater than the loads reaching the Lake under presettlement conditions. Similarly, modern day sediment loads are about 16 times higher than presettlement loads.

Based upon 1963 watershed land use, the UAL model estimates that 4,793 tons of sediment and 18,744 pounds of non-point source phosphorus per year were entering the Lake each year with surface water. In addition, the DelaHart wastewater treatment plant was contributing an additional 8,000 pounds of phosphorus to the Lake each year as determined in 1974 by the USEPA.[98] In contrast, the UAL model predicts that, under year 2010 land use conditions, 2,986 tons of sediment and 12,521 pounds of phosphorus were delivered to Nagawicka Lake with surface-water runoff, 60 percent less sediment and 68 percent less phosphorus compared to 1963 land use conditions. In 2010, agricultural land uses contributed about 67 percent of the sediment and about 61 percent of the phosphorus reaching Nagawicka Lake.

Figure 2.46
Relative Contributions of External Sediment Sources to Nagawicka Lake



Note: Sediment loads were not directly measured but instead estimated using assumed and modeled values from similar systems.

Source: SEWRPC

Map 2.26 highlights parcels that the UAL model suggests contribute more phosphorus per acre of land. Phosphorus and sediment loads contributed by each acre of sub-basin are compared in Figures 2.48 and 2.49, respectively. According to the UAL model, sub-basins 3, 5, 6, and 7 had the highest phosphorus and sediment loading per acre. Urban land use contributes more to phosphorus and sediment loading in sub-basins 5, 8, and 10 while agricultural land use is the dominant phosphorus and sediment contributor in sub-basins 1, 2, 3, 4, and 9. Urban and agricultural land uses contribute similarly to phosphorus and sediment loading in sub-basins 6, 7, and 11.

Under planned conditions, agricultural lands will be converted to urban land use, and the overall mass of sediment and phosphorus from agricultural land that is delivered to Nagawicka Lake will decrease by about 37 percent and 26 percent, respectively. With proactive and aggressive pursuit of runoff water quality measures, sediment and phosphorus loading to the Lake can be further reduced. Practices to reduce urban loading are addressed in more detail in Chapter 3.

[97] Ibid.

[98] *US EPA, 1974,* op. cit.

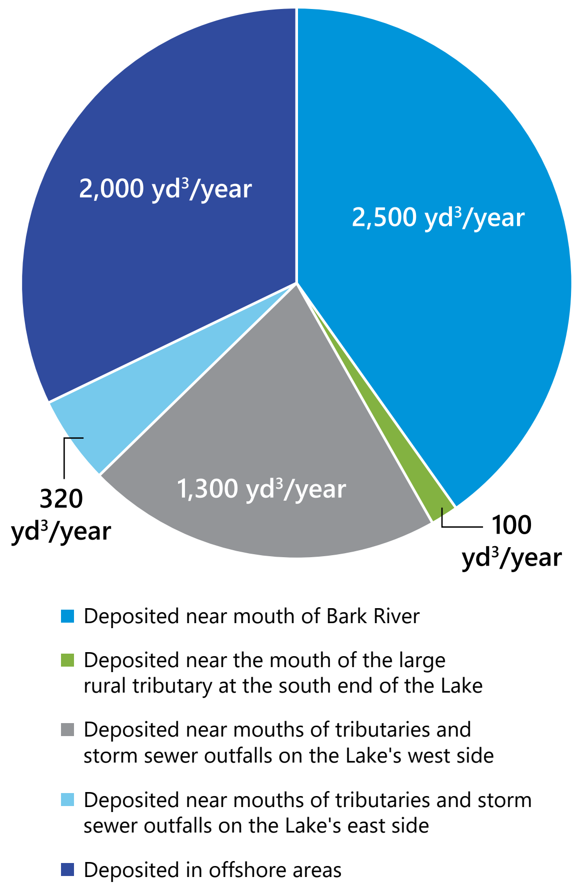
The Wisconsin Lake Model Suite (WiLMS) can also be used to estimate phosphorus loading to the Lake. Similar to the approach employed by the UAL model, land use, hydrologic, and watershed area information are used to estimate the total flux of phosphorus to a lake during a typical year.[99] The WiLMS model produces a range of probable phosphorus *load* values (low, most likely, and high). Load estimates are then used to predict water quality in the receiving lake using several regression equations. The regression equations have been designed to fit a variety of lake types. For example, some are designed for reservoirs, some for deep lakes, while others are general lake models.

<u>Load Comparison</u>

For 2010 land use conditions, the WiLMS model predicts between 7,357 and 21,774 pounds of phosphorus could be delivered to Nagawicka Lake per year. The middle-range value of 13,634 pounds predicted by the WiLMS model essentially matches closely the 12,521 pounds estimated by the UAL model. However, the WDNR's Pollutant Load Estimation Tool (PRESTO Lite) estimates that the amount of phosphorus entering the lake per year falls somewhere between 1,626 and 8,218 pounds.[100] This agrees closely with daily measurements taken by the USGS from October of 2002 to September of 2006 that indicate that an average of seven pounds of phosphorus is delivered per day to Nagawicka Lake, amounting to an average of 2,559 pounds per year. The phosphorus load fluctuates along with the average daily flow of the River (Figure 2.44).

The USGS has found that models tend to over-predict loading for calcareous lakes and would suggest that the low range values for WiLMS may better portray conditions in the watershed. Therefore, the low range values were also used to predict present and future water quality of the Lake.

Figure 2.47
Fate of Nagawicka Lake External Sediment Loads



Note: Sediment loads were not directly measured but instead estimated using assumed and modeled values from similar systems.

Source: SEWRPC

Using the low-range loading estimates for the reason discussed above, the Walker Reservoir regression-based model used for the USGS study best fits observed conditions in Nagawicka Lake.[101,102] However, the model predicts growing season mean phosphorus values of 29 μg/L, a value which is 2.1 times higher than the average observed value of 14 μg/L. The USGS study on Nagawicka Lake found that their models consistently over predicted phosphorus by a factor of 2.2,[103] a discrepancy which is likely due to the co-precipitation

[99] *These models do not account for groundwater influx and exit from the lake. Models can be manipulated to include this variable if sufficient interest is expressed by lake users and managers as part of a future study. Groundwater is a very important component of the water budget of Nagawicka Lake. Including groundwater in future models may not necessarily improve the accuracy of the models, but will account for and potentially eliminate a currently untested variable from the simulation process.*

[100] *Wisconsin Department of Natural Resources, PRESTO-Lite Watershed Delineation Report, Bark River watershed, 2018.*

[101] *W.W. Walker Jr., "Statistical Bases from Mean Chlorophyll-a Criteria, In Lake and Reservoir Management: Practical Applications,"* North American Lake Management Society, *pages 57-62, 1985.*

[102] *D.P. Larsen and H. T. Mercier, "Phosphorus Retention Capacity of Lakes,"* Journal of the Fisheries Research Board of Canada *33: 1742-1750, 1976.*

[103] *Garn, 2006,* op. cit.

Table 2.16
Presettlement (circa 1835), Current (2010), and Planned Future Sediment, Phosphorus, and Pollutant Loads to Nagawicka Lake

Pollutant Loads: Presettlement				
Land Use Category	Sediment (tons/year)	Phosphorus (pounds/year)	Copper (pounds/year)	Zinc (pounds/year)
Urban				
Residential[a]	0.0	0.0	0.0	0.0
Commercial	0.0	0.0	0.0	0.0
Industrial	0.0	0.0	0.0	0.0
Governmental	0.0	0.0	0.0	0.0
Transportation	0.0	0.0	0.0	0.0
Recreational	0.0	0.0	0.0	0.0
Subtotal	0.0	0.0	0.0	0.0
Rural				
Agricultural	0.0	0.0	0.0	0.0
Wetlands	0.0	0.0	0.0	0.0
Woodlands	52.3	1180.1	0.0	0.0
Subtotal	52.3	1,180.1	0.0	0.0
Atmospheric Deposition				
Nagawicka Lake Surface	94.9	131.3	0.0	0.0
Other Water Bodies Surface	35.3	48.9	0.0	0.0
Subtotal	130.2	180.2	0.0	0.0
Total	182.5	1,360.3	0.0	0.0

Pollutant Loads: 2010				
Land Use Category	Sediment (tons/year)	Phosphorus (pounds/year)	Copper (pounds/year)	Zinc (pounds/year)
Urban				
Residential[a]	124.2	1,789.5	30.2	320.1
Commercial	501.8	1,536.0	281.6	1,907.2
Industrial	82.7	257.4	48.4	327.8
Governmental	121.9	644.0	33.4	381.6
Transportation	0.0	0.0	0.0	0.0
Recreational	9.3	209.8	0.0	0.0
Subtotal	839.9	4,436.7	393.6	2,936.7
Rural				
Agricultural	2,004.3	7,660.9	0.0	0.0
Wetlands	5.6	121.1	0.0	0.0
Woodlands	5.6	121.8	0.0	0.0
Subtotal	2,015.5	7,903.8	0.0	0.0
Atmospheric Deposition				
Nagawicka Lake Surface	94.9	131.3	0.0	0.0
Other Water Bodies Surface	35.3	48.9	0.0	0.0
Subtotal	130.2	180.2	0.0	0.0
Total	2,985.6	12,520.7	393.6	2,936.7

Table continued on next page.

of phosphorus with calcite and the sequestration of phosphorus in deep sediments. It is also possible that external loading may have high amounts of non-available phosphorus.

The regression models that best predicted observed growing season mean phosphorus values were next used to predict water quality of the Lake under planned land use conditions. The Walker Reservoir Model predicts a slight decrease (1 μg/L) in Nagawicka Lake's growing season mean phosphorus concentrations under the planned land use conditions analyzed by the USGS. These estimates suggest that planned land use conditions will not significantly change summer phosphorus concentrations in the Lake on their own. It must be noted that these predictions are based solely on watershed conditions, and do not include factors

Table 2.16 (Continued)

Land Use Category	Pollutant Loads: Planned Sediment (tons/year)	Phosphorus (pounds/year)	Copper (pounds/year)	Zinc (pounds/year)
Urban				
Residential[a]	168.4	2,483.9	51.1	450.5
Commercial	214.8	657.6	120.6	816.5
Industrial	506.8	1,577.2	296.6	2,008.5
Governmental	190.6	1,061.7	52.2	596.8
Transportation	0.0	0.0	0.0	0.0
Recreational	10.5	236.0	0.0	0.0
Subtotal	1,091.1	6,316.4	520.5	3,872.3
Rural				
Agricultural	640.8	2,610.3	0.0	0.0
Wetlands	5.6	121.0	0.0	0.0
Woodlands	5.6	121.1	0.0	0.0
Subtotal	652.0	2,852.4	0.0	0.0
Atmospheric Deposition				
Nagawicka Lake Surface	94.9	131.3	0.0	0.0
Other Water Bodies Surface	35.3	48.9	0.0	0.0
Subtotal	130.2	180.2	0.0	0.0
Total	1,873.3	9,349.0	520.5	3,872.3

[a] *Includes low density, medium density, high density, and multi-family residential land use.*

Source: SEWRPC

such as changes to rough fish control, revised shoreline and agricultural practices, aquatic plant harvesting, and other management tools. If a stringent set of stormwater water quality practices is required for new development, there is a chance to decrease phosphorus loading to the Lake, even with the additional development. This can be further reinforced through widespread use of residential, agricultural, and open land best management practices.

Planned land use for Nagawicka Lake are shown on Map 2.18.[104] A moderate portion of agricultural land is planned to be developed around Nagawicka Lake. As summarized in Table 2.11, agricultural land uses within the adjusted Nagawicka Lake watershed are expected to decrease from about 23 percent of the land area in 2010, to about 10 percent of the land area in planned land use. The anticipated land use changes would involve conversion of agricultural and open lands to urban, largely residential, uses. Table 2.16 indicates the possibility of modest reductions in annual sediment and phosphorus loads due primarily to planned land use changes and increases in heavy metals contributed by urban land uses. There is also a potential for transient increased sediment pollution related to erosion during construction associated with the conversion of land from agricultural to residential uses. Consequently, recommendations to mitigate these risks and ensure the health of the Lake are included in Chapter 3.

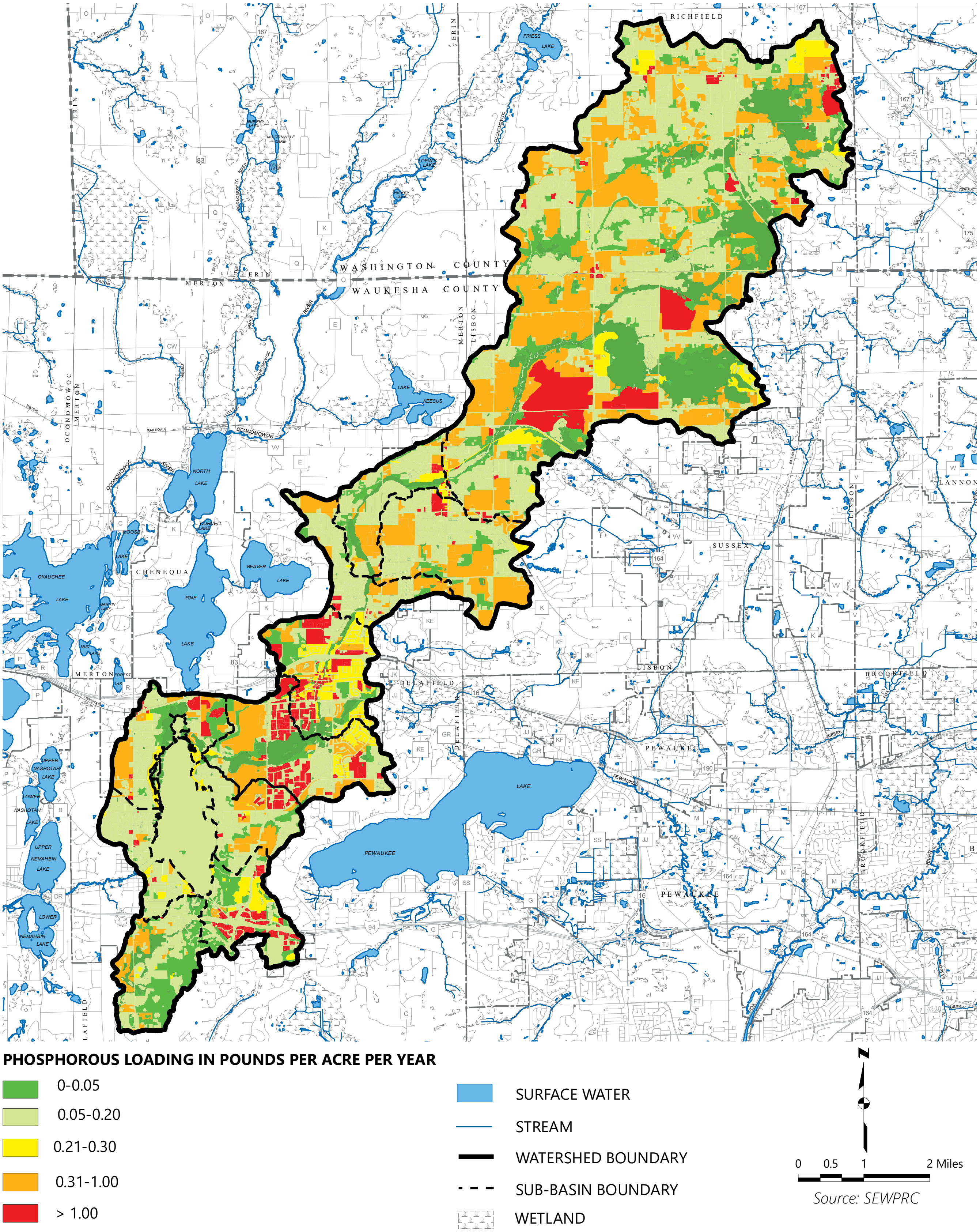
Finally, some of the northeastern watershed areas are outside of the planned sewer service area. Without proper maintenance, septic systems can malfunction possibly causing bacterial contamination and increased phosphorus loadings to the Lake and the groundwater. Therefore, management of current systems and any new systems is discussed in Chapter 3 of this report.

Phosphorus Removal Through Aquatic Plant Harvesting

A benefit of aquatic plant harvesting versus chemical treatment is that harvesting physically removes plant mass, and the nutrients contained therein, from the Lake. In some lakes, plant harvesting removes enough phosphorus to tangibly reduce lake phosphorus loads. Plant harvesting is already underway in the Lake for navigation purposes (see Table 2.17). The Commission calculated the pounds of total phosphorus removed through harvesting by multiplying the annual mass of aquatic plant removed by the phosphorus concentration of those aquatic plants, with the following notes and assumptions:

[104] *See SEWRPC Planning Report No. 48*, A Regional Land Use Plan for Southeastern Wisconsin: 2035, *June 2006.*

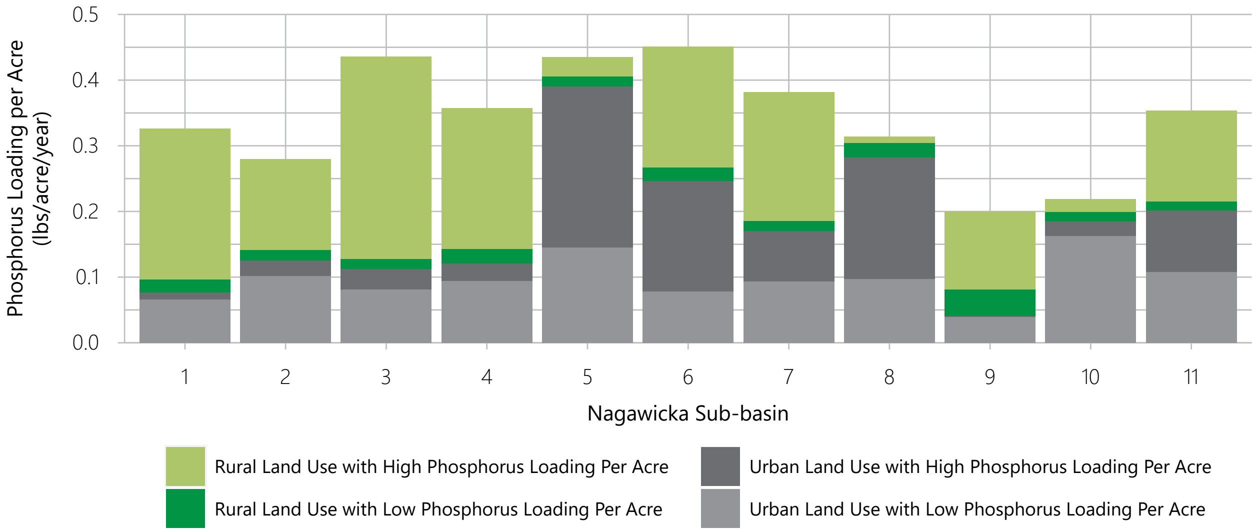
Map 2.26
Gross Phosphorus Loads Predicted by Land Use in the Nagawicka Lake Watershed



Source: SEWPRC

Note: Gross phosphorus loading rates are derived from the Commission's Unit Area Loading (UAL) model. Phosphorus loads reaching nearby waterbodies may be reduced by a wide variety of factors. For example, the internally drained areas may generate high gross phosphorus yields but may not deliver any phosphorus to nearby waterbodies.

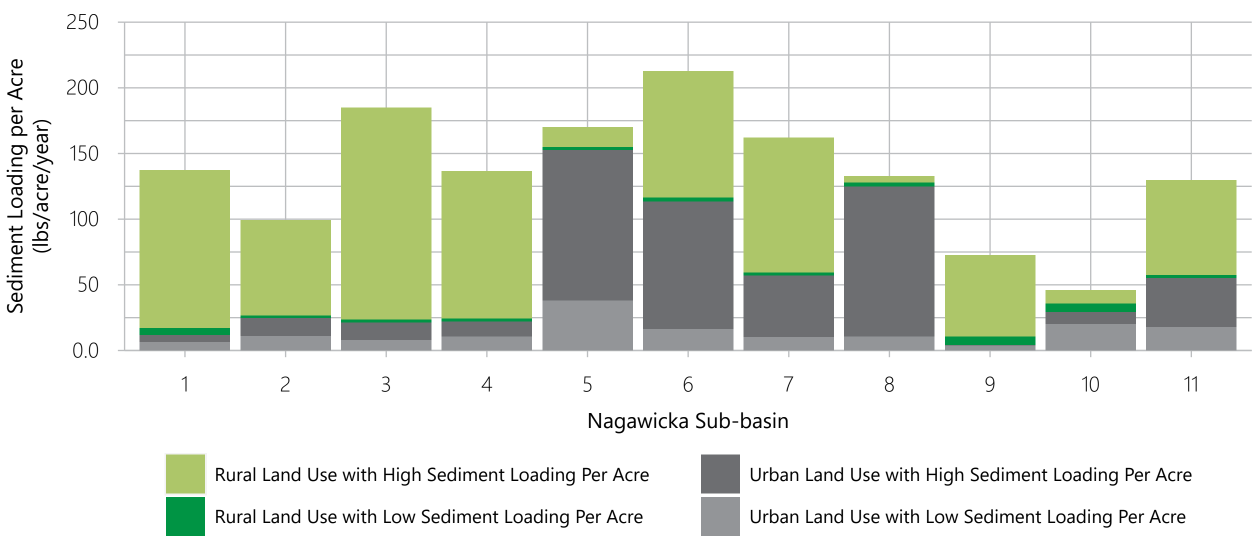
Figure 2.48
Phosphorus Loading per Acre in Nagawicka Sub-Basins



Note: Gravel pits were considered internally draining and thus were not added to this analysis.

Source: SEWRPC

Figure 2.49
Sediment Loading per Acre in Nagawicka Sub-Basins



Note: Gravel pits were considered internally draining and thus were not added to this analysis.

Source: SEWRPC

- The density of the wet harvested plants was assumed to be 900 pounds per cubic yard.

- The amount of phosphorus contained by aquatic plants varies by species, lake, and time. The phosphorus content of harvested plants used estimates from the Wisconsin Lutheran College (WLC) on Pewaukee Lake, the U.S. Geological Survey on Whitewater and Rice lakes (Whitewater-Rice), and a study conducted on a eutrophic lake in Minnesota (Minnesota). The WLC study assumed that plant wet weight is 6.7 percent of dry weight and that total phosphorus constitutes 0.2 percent of the total dry weight of the plant. The Whitewater-Rice and Minnesota studies assumed that dry weight is 15 and 7 percent of the wet weight, respectively, and phosphorus constituted 0.31 and 0.30 percent of the dry plant weight, respectively. Assumed values for the percent of dry weight to wet weight and the total phosphorus concentrations are similar to those found other studies.[105,106]

Using this method, the Commission estimates that aquatic plant harvesting removes an average of 222 to 772 lbs. of phosphorus each year, for a cumulative phosphorus removal of 3,558 to 12,346 lbs. since 2003 (see Figure 2.50). The WDNR's Presto-Lite tool estimates that the average total annual phosphorus load to the Lake ranges between 1,626 to 8,218 lbs. per year. Therefore, aquatic plant harvesting may remove between 3 to 47 percent of the total phosphorus load each year. The cumulative impact of annually removing phosphorus from the Lake through harvesting is significant. Improvements in water clarity, phosphorus, and chlorophyll-*a* measurements on the Lake indicate that phosphorus removal through aquatic plant harvesting may be helping to offset phosphorus inputs.

Table 2.17
Volume of Aquatic Plants Removed by Harvesting, Nagawicka Lake: 2003 – 2018

Year	Volume of Aquatic Plants Harvested (cubic yards)
2003	1,650
2004	1,755
2005	2,110
2006	1,790
2007	2,250
2008	1,280
2009	2,140
2010	2,550
2011	2,080
2012	1,930
2013	1,490
2014	1,465
2015	1,560
2016	1,955
2017	1,835
2018	1,660
Total	29,500

Source: City of Delafield and SEWRPC

Water Quality Summary

Available data strongly suggests that phosphorus delivered to the Lake by flowing water is the leading contributor to the Lake's overall phosphorus supply. Lake-direct drainage areas contribute the most phosphorus to the Lake on an acre-by-acre basis. Therefore, management actions in the area immediately surrounding the Lake have the highest potential for incrementally reducing the mass of phosphorus reaching the Lake, but actions anywhere in the watershed that reduce phosphorus loading to the Lake are beneficial.

Internal phosphorus loading and/or phosphorus recycling may also contribute to summer phosphorus concentrations. Phosphorus internal loading and recycling is a problem in many deep, thermally stratified lakes. Many approaches have been developed to help mitigate its effects on water quality. To be truly effective and long lasting, any effort to reduce phosphorus internal loading must be predicated by, or be accompanied with, efforts that permanently reduce and control external phosphorus loading. If a lake receives heavy phosphorus inputs from its watershed or point sources, any improvement in lake health from internal load/recycling reduction efforts will be short lived.

Because of hard water and the types of aquatic plants found Nagawicka Lake, the Lake has an outstanding ability to absorb phosphorus and deposit it to the Lake bottom. This very important feature maintains the Lake's health by reducing the potential for undesirable algal blooms. The Lake's phosphorus sequestration process is highly dependent upon ample groundwater discharge, clear water, and abundant muskgrass (*Chara* spp.) growth. Furthermore, aquatic plant harvesting may be removing substantial amounts of phosphorus from the Lake. Therefore, these factors should be prime management concerns.

2.3 NEARSHORE AND STREAM CHANNEL INVENTORY

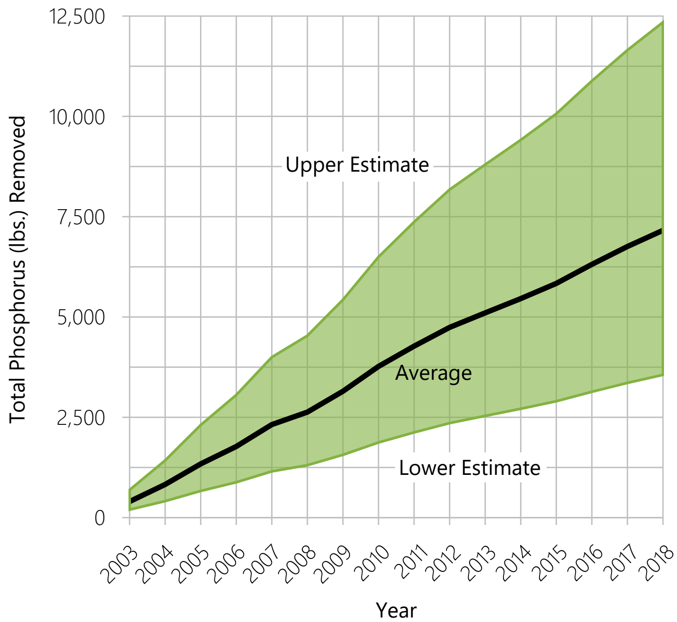
Between July and October 2016, Commission staff completed on-the-water inventories to collect a variety of information regarding Nagawicka Lake and the Bark River. These inventories included all of Nagawicka Lake (see Map 2.27) and the Bark River from the outlet into Nagawicka Lake upstream to the Merton Millpond (approximately 8.5 linear stream miles, see Map 2.28). The effort quantitatively and qualitatively characterized aquatic plants (see Section 2.4, "Aquatic Plant Management" for more details), sediment depth and composition, water depths, lake shoreline and streambank conditions, riparian buffers, and other features such as stormwater outfalls, trash and debris, and channel obstructions/navigational hazards. Effort was focused on identifying potential project sites or areas where activities could tangibly improve the

[105] *K.M. Carvalho and D.F. Martin, "Removal of Aqueous Selenium by Four Aquatic Plants," Journal of Aquatic Plant Management 39: 33-36, 2001.*

[106] *G. Thiébaut, "Phosphorus and Aquatic Plants," In P.J. White and J.P. Hammond (eds), The Ecophysiology of Plant-Phosphorus Interactions,* Plant Ecophysiology *7, 2008.*

water quality and ecology. Where appropriate, features were located using a handheld GPS device and photographed (see Appendix A).

Figure 2.50
Phosphorus Removal by Harvesting: 2003 – 2018



Source: City of Delafield and SEWRPC

Nagawicka Lake

Shoreline Protection Basics

Many property owners abutting Nagawicka Lake struggle to maintain the Lake's shorelines and overall recreational use, and aesthetic appeal without jeopardizing Lake health. This issue of concern is underscored by the fact that Lake water quality, Lake sedimentation, and aquatic plant growth are all influenced by shoreline maintenance practices.

Before discussing shoreline characteristics, it is important to understand the difference between two terms: *shoreline protection* and *buffers*. *Shoreline protection* encompasses various measures—engineered or natural—that shield the immediate shoreline (land-water interface) against erosive forces of wave action. *Buffers* are areas of plant growth—engineered or natural—in the riparian zone (lands immediately back from the shoreline) that trap sediment and nutrients emanating from upland and nearshore erosion. Buffers were described in detail earlier in this report.

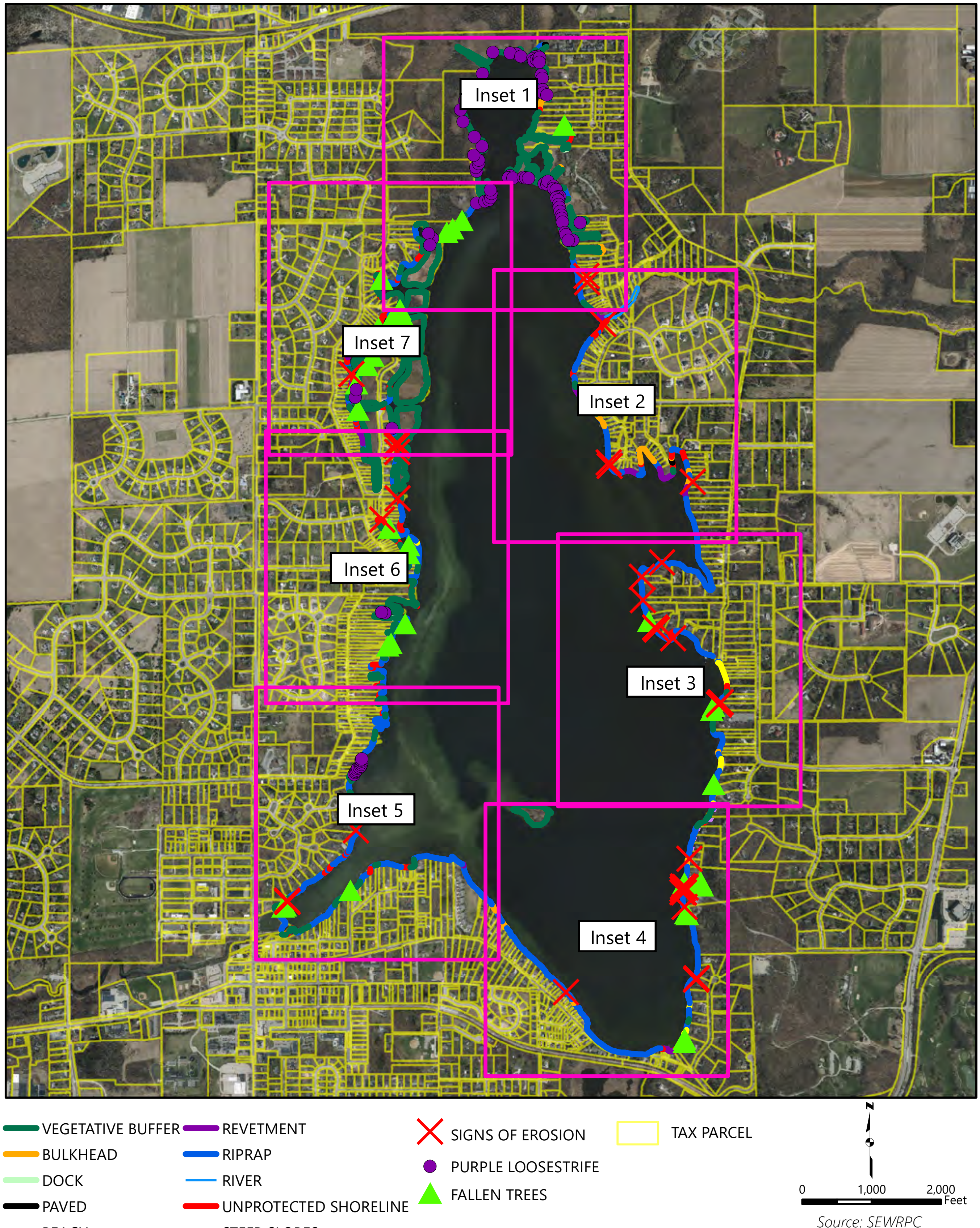
Engineered seawalls constructed of stone, riprap, concrete, timbers, and steel, once considered "state-of-the-art" shoreline protection, are now recognized as only one option to protect lake shorelines from erosion. Other alternatives provide benefits beyond shoreline erosion and are better suited to restore a lake's water quality, wildlife, recreational opportunities, and scenic beauty. Indeed, the inability of hard shorelines to absorb wave energy causes many engineered seawalls to reflect wave energy back into a lake, increasing wave energy in other shoreline areas. Incorporating vegetation, either in front of or embedded into the hard structures, improves shoreline stability and providers better wildlife habitat in the nearshore area. Manmade engineered options available to home owners include "bulkheads," where a solid *vertical* wall of erosion-resistant material (e.g., poured concrete, steel, or timber) is erected; "revetments," where a solid, *sloping* wall (usually asphalt, as in the case of a roadway, or poured concrete) is installed; and "riprap," where loose stone material is placed along the shoreline (see Figure 2.51). However, these options are only available with a WDNR permit.

More recently, "soft" shoreline protection techniques, referred to as "vegetative shoreline protection" (see Figure 2.52), utilizing combinations of materials, including native plantings, are increasingly required pursuant to Chapter NR 328, "Shore Erosion Control Structures In Navigable Waterways," of the *Wisconsin Administrative Code*. Vegetative shoreline protection is gradually supplanting hard protection landowners along lakes and streams become increasingly aware of the multifaceted value of protecting shorelines, improving views and overall aesthetic appeal, and promoting natural and nature-like habitat for wildlife. Additionally, shorelines protected with vegetation help shield a lake from both upland and shoreline pollutant/sediment sources.

Given the benefits of "soft" shoreline protection measures, the WDNR no longer permits construction of new "hard" structures in lakes that do not have extensive wave action threatening the shoreline. However, existing structures may be repaired. Consequently, the recommendations in this plan related to shoreline restoration focus on "soft" measures including native plantings, maintaining aquatic plants along shorelines, and using "bio-logs" (see Appendix B). Beach areas, which legally need to be made from pea gravel,[107] are considered as a separate category. Placing pea gravel may be permitted; however, this must be evaluated by WDNR on a case-by-case basis.

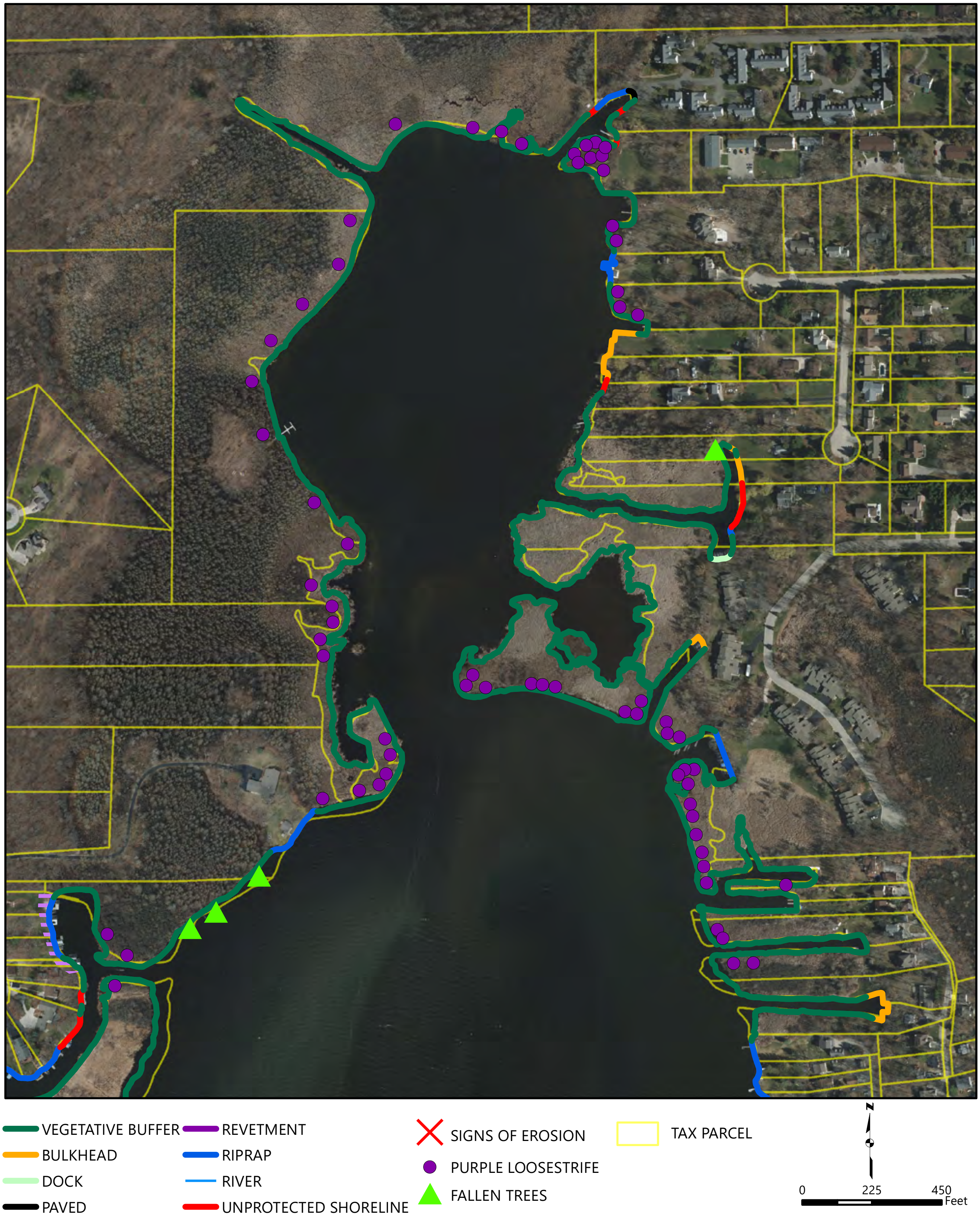
[107] *WDNR does not permit the use of sand because these materials quickly flow into a waterbody and contribute to the "fill-in" of the Lake.*

Map 2.27
Nagawicka Lake Shoreline Characteristics Overview: 2016



Source: SEWRPC
Date of Photography: April 2015

Map 2.27 (Inset 1)
Nagawicka Lake Shoreline Characteristics Detail: Northern Portion, 2016



Source: SEWRPC
Date of Photography: April 2015

Map 2.27 (Inset 2)
Nagawicka Lake Shoreline Characteristics Detail: Eastern Portion/Zastrow Bay, 2016

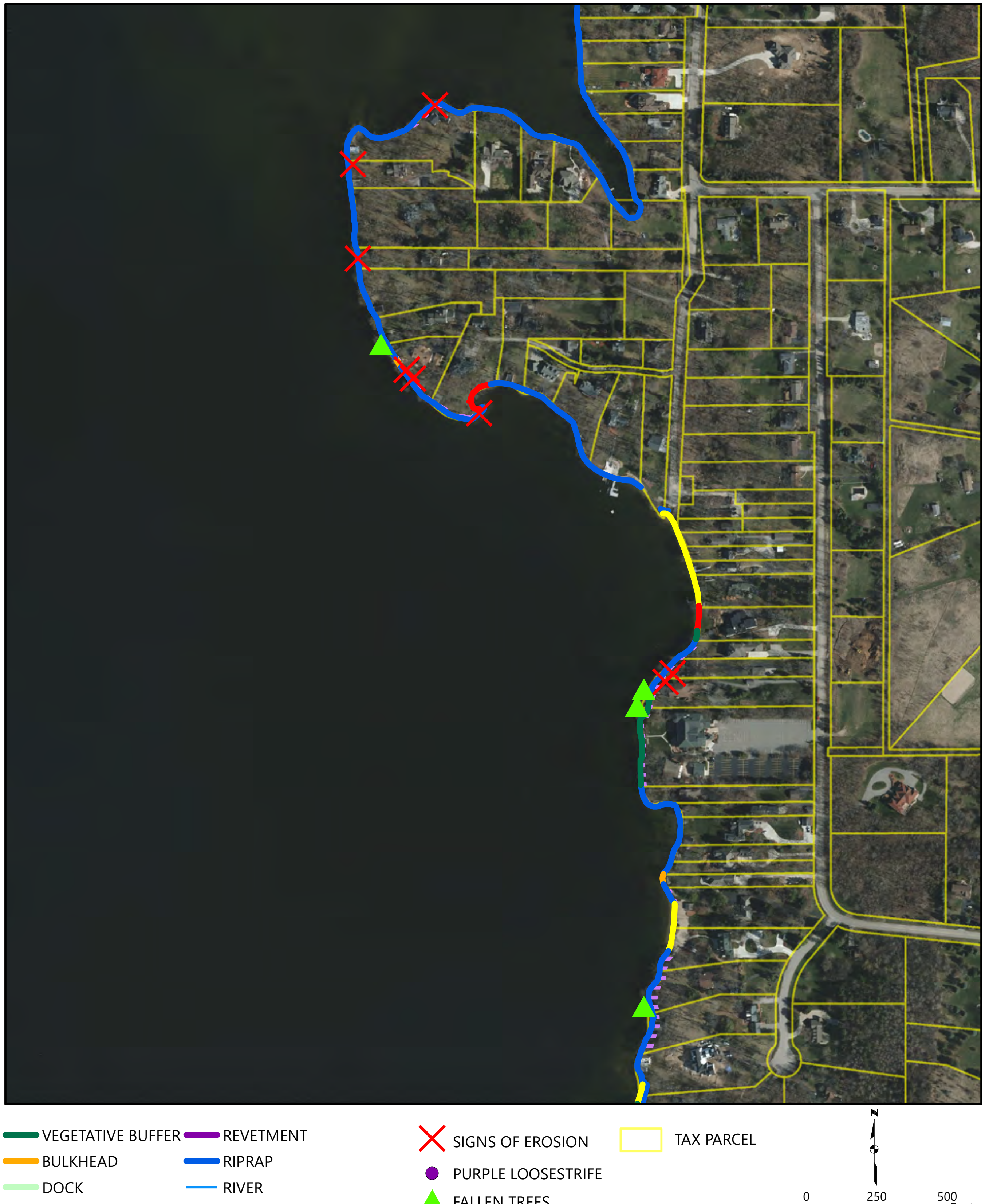
VEGETATIVE BUFFER
BULKHEAD
DOCK
PAVED
BEACH
REVETMENT
RIPRAP
RIVER
UNPROTECTED SHORELINE
STEEP SLOPES
SIGNS OF EROSION
PURPLE LOOSESTRIFE
FALLEN TREES
TAX PARCEL

N

0 225 450 Feet

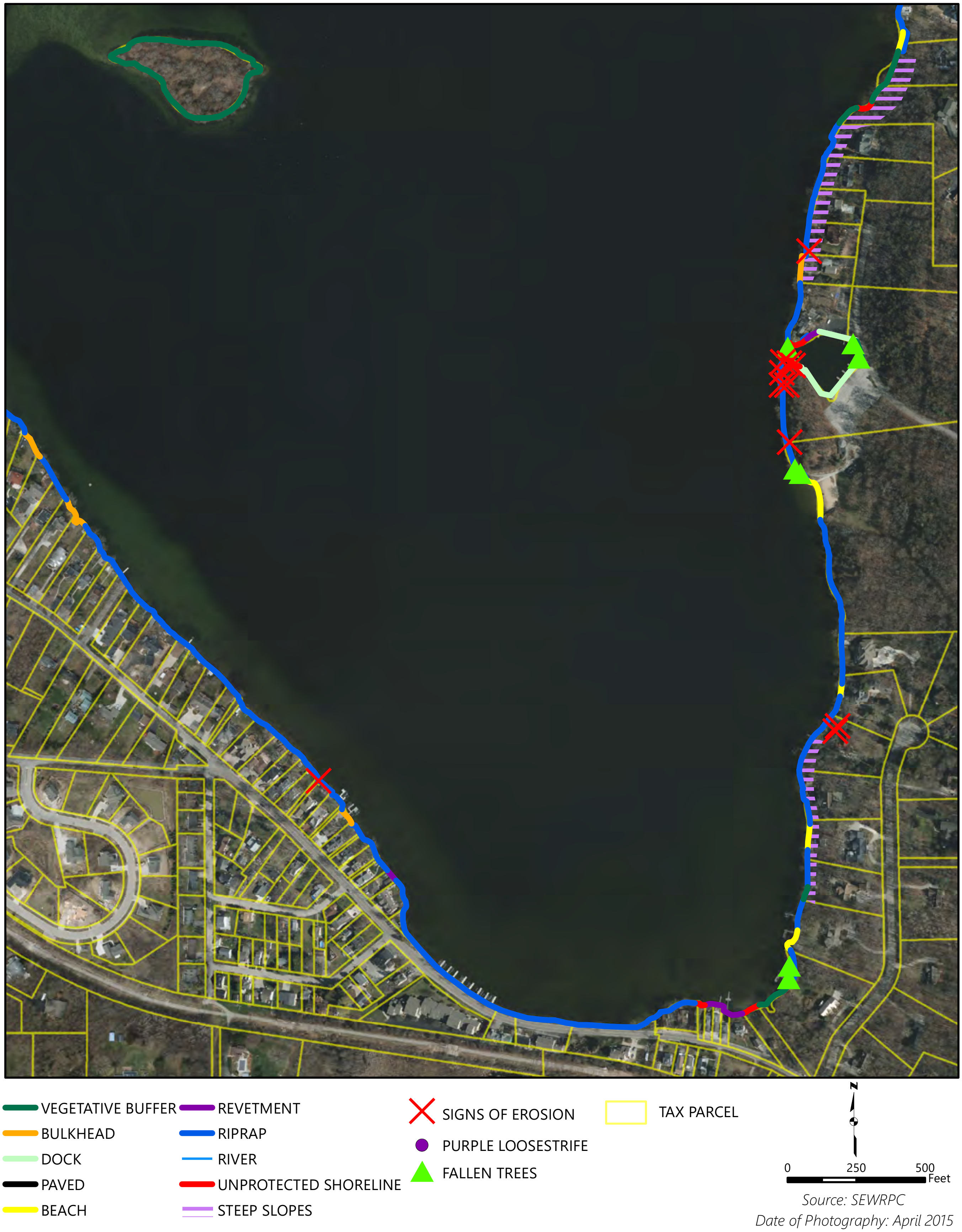
Source: SEWRPC
Date of Photography: April 2015

Map 2.27 (Inset 3)
Nagawicka Lake Shoreline Characteristics Detail: Eastern Central Portion, 2016



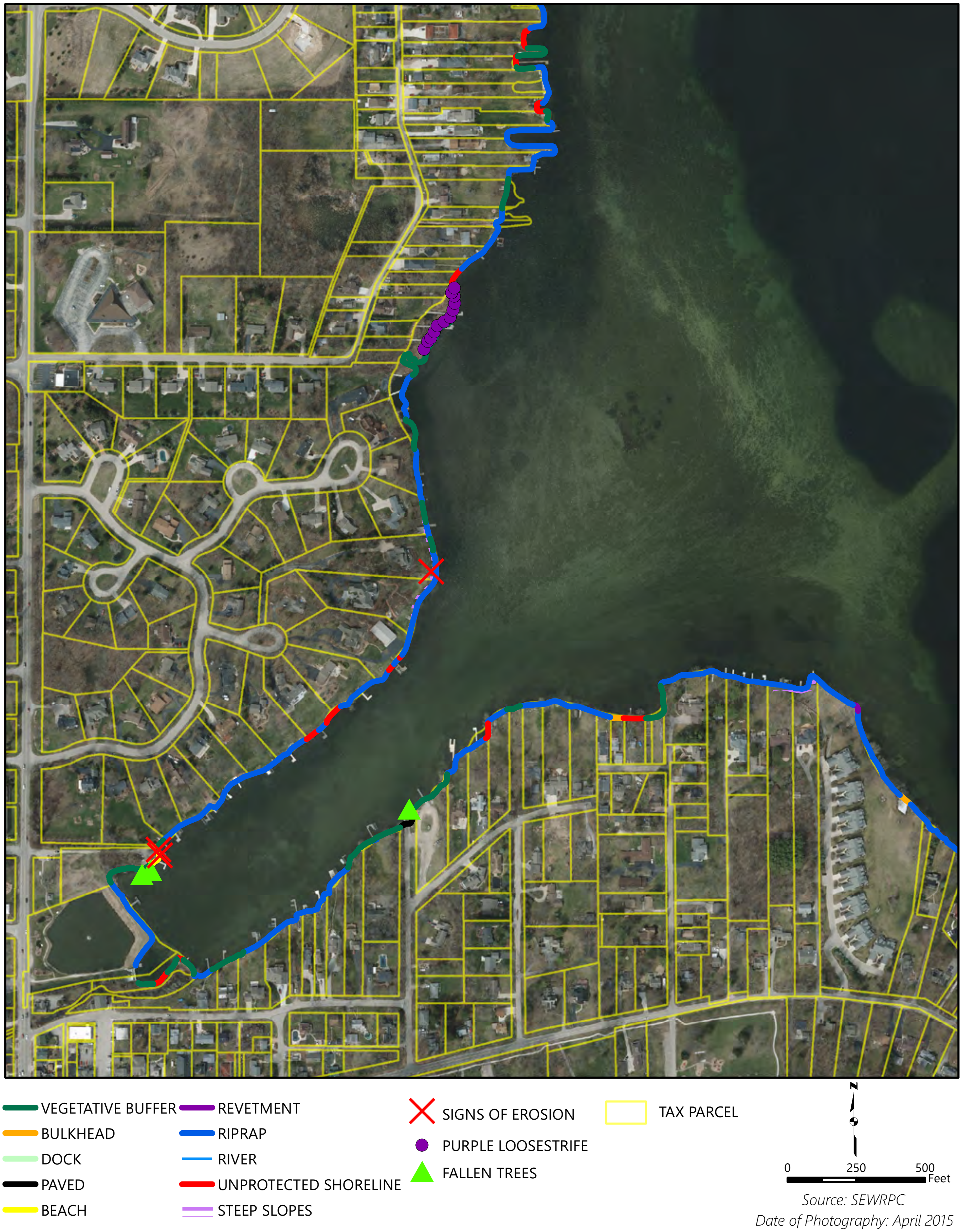
Source: SEWRPC
Date of Photography: April 2015

Map 2.27 (Inset 4)
Nagawicka Lake Shoreline Characteristics Detail: Southern Portion, 2016



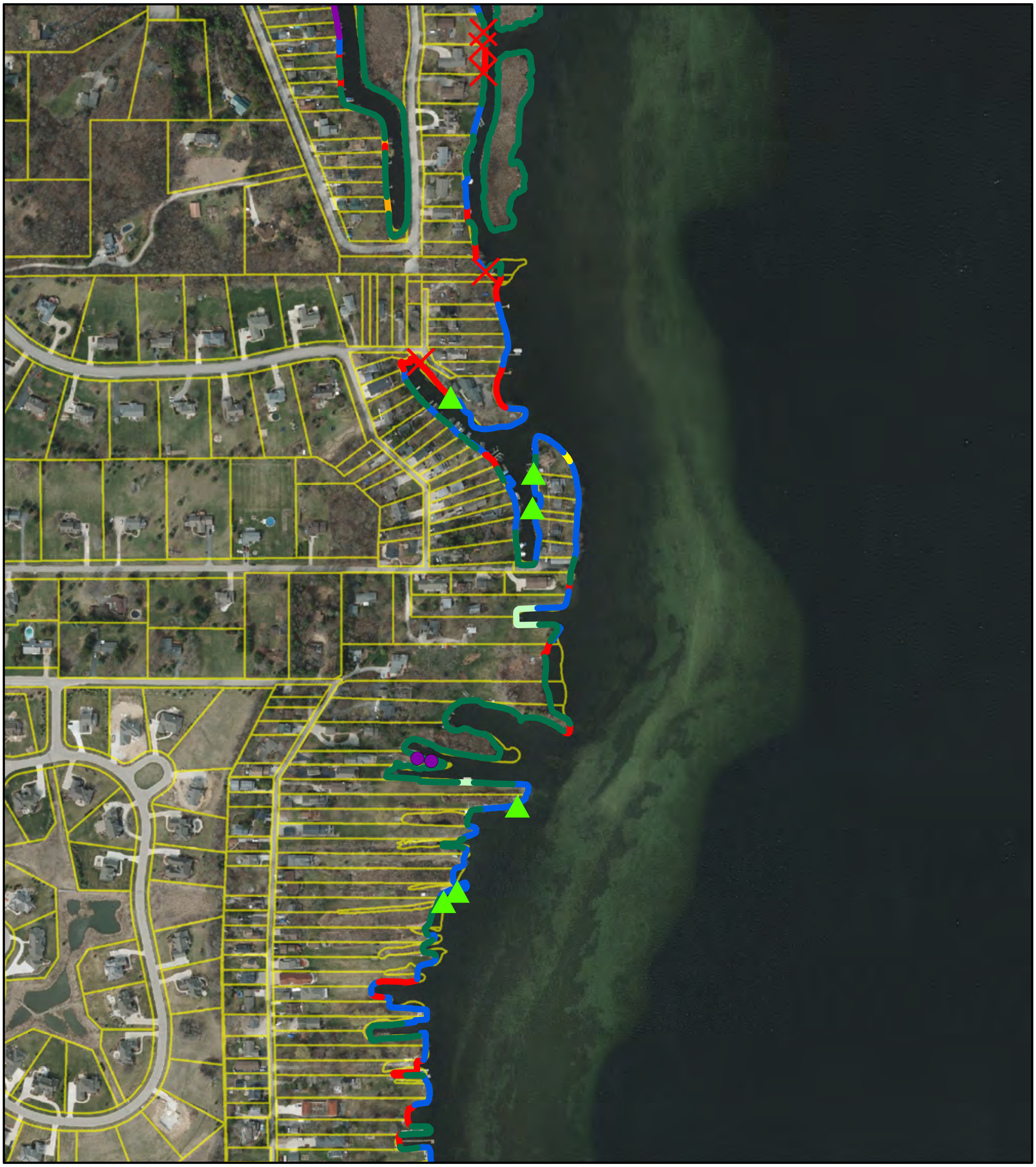
Source: SEWRPC
Date of Photography: April 2015

Map 2.27 (Inset 5)
Nagawicka Lake Shoreline Characteristics Detail: Southwestern Portion/Lake Outlet, 2016



Source: SEWRPC
Date of Photography: April 2015

Map 2.27 (Inset 6)
Nagawicka Lake Shoreline Characteristics Detail: West Central Portion, 2016

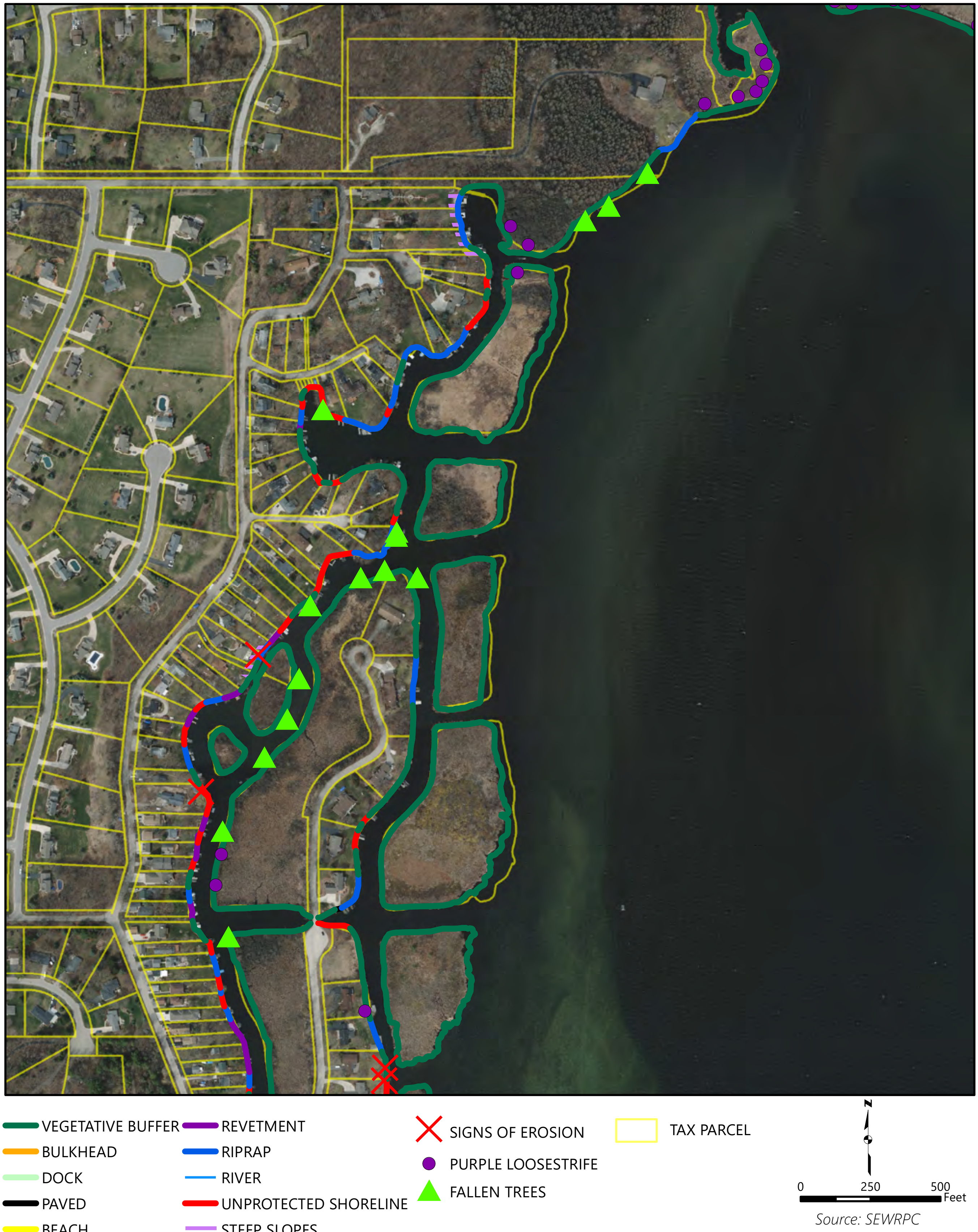


VEGETATIVE BUFFER
BULKHEAD
DOCK
PAVED
BEACH
REVETMENT
RIPRAP
RIVER
UNPROTECTED SHORELINE
STEEP SLOPES
SIGNS OF EROSION
PURPLE LOOSESTRIFE
FALLEN TREES
TAX PARCEL

0 250 500 Feet

Source: SEWRPC
Date of Photography: April 2015

Map 2.27 (Inset 7)
Nagawicka Lake Shoreline Characteristics Detail: Northwestern Portion, 2016



Source: SEWRPC
Date of Photography: April 2015

Map 2.28
Bark River On-The-Water Inventory: September 2016

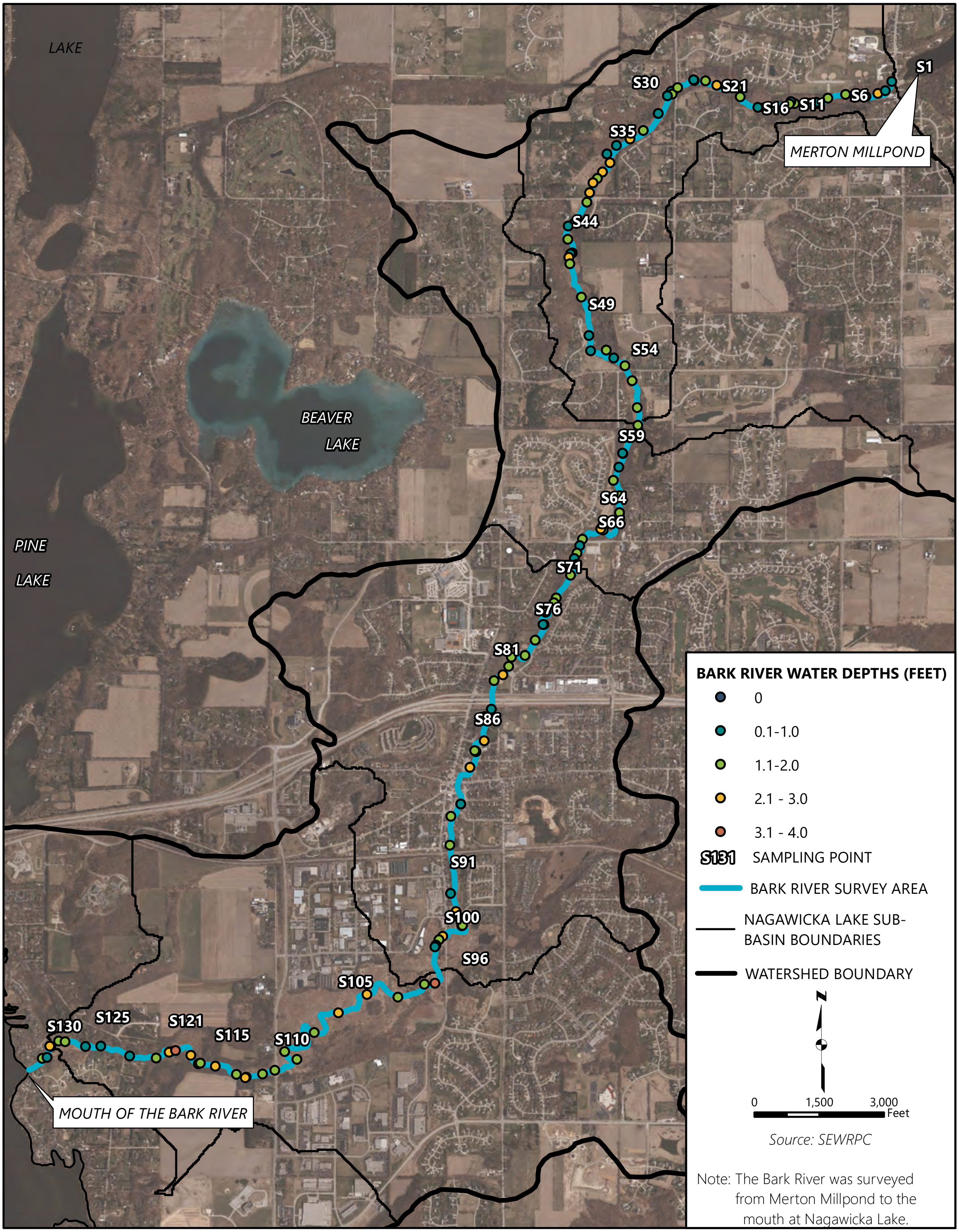
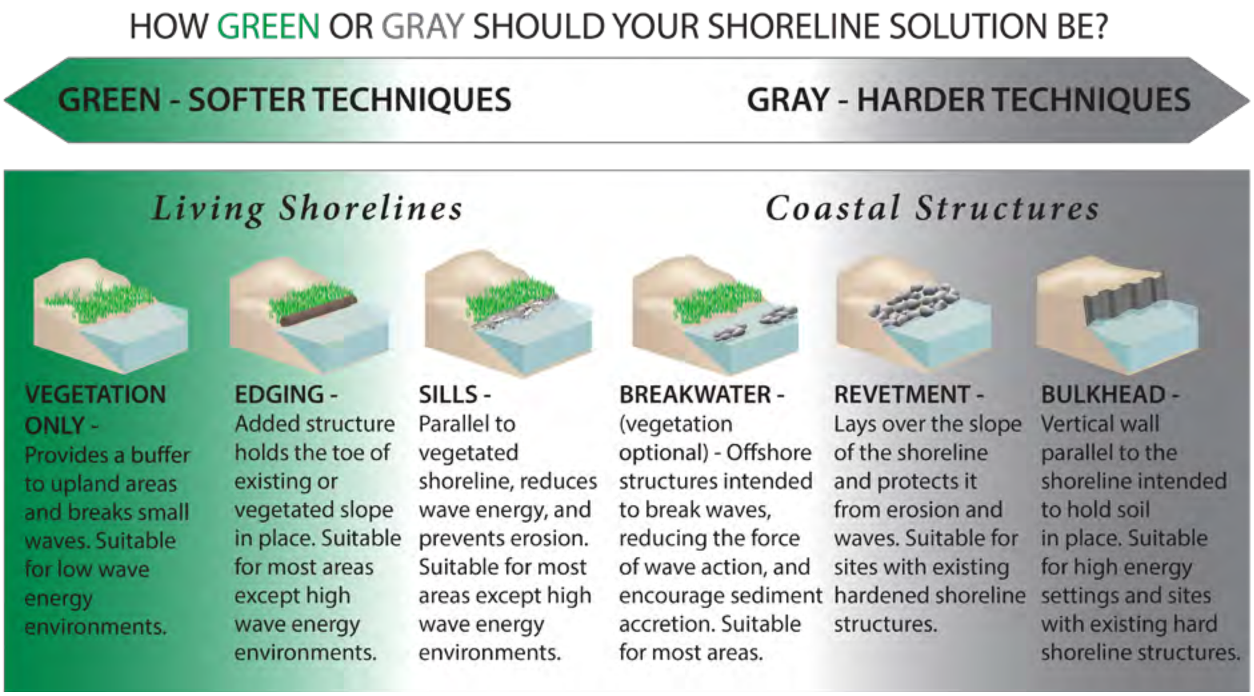


Figure 2.51
"Living Shorelines" Protection Techniques



Source: National Oceanic and Atmospheric Administration (NOAA) and SEWRPC

It must be emphasized that, in certain cases, shoreline protection does not have to rely on artificial, engineered structures. Many types of natural shorelines offer substantial protection against erosive force. For example, boulders and rock cliffs function as natural rip-rap or bulkheads. Additionally, wetlands and areas of exposed cattail stalks and lily pads effectively reduce shoreline erosion by dissipating and absorbing wave energy.

Key Inventory Findings

The results of the Nagawicka Lake shoreline survey are summarized on Map 2.27. From this information, the following conclusions are drawn.

- Fifty-two percent of the Lake shoreline already has vegetative buffer. However, 62 percent of the tax parcels (301 parcels) adjacent to the Lake shore had absolutely no vegetative buffer. Unbuffered parcels are prime opportunities to expand adoption of shoreline management practices that reduce erosion and runoff.

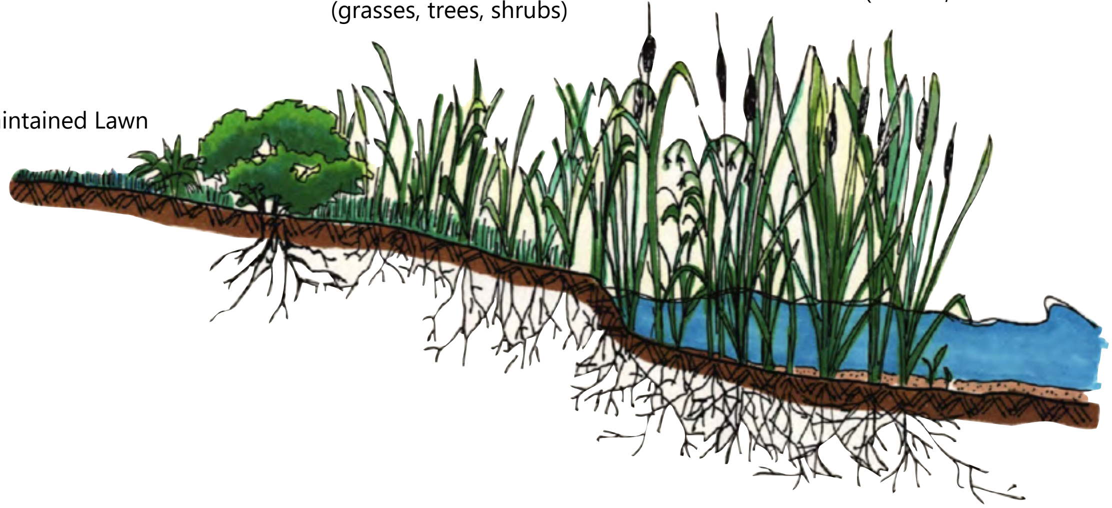
- Areas of visibly eroding shoreline were scattered around the Lake but are most prevalent on the Lake's eastern shoreline. This may be related to prevailing wind conditions, wave action dynamics, topography, and soil conditions.

- Purple loosestrife grew in greatest abundance in the northern kettle, although it was also found sporadically along the southwestern and western shorelines.

- Fallen trees (a positive habitat feature) were concentrated on the western shoreline, particularly in the western channels. Some fallen trees were also scattered along the eastern shoreline. Nonetheless, on a lake wide basis, large woody structure was largely lacking from Lake nearshore areas.

- Shorelines buffered by vegetation were most common along the northern and northwestern shorelines of Nagawicka Lake. Very few areas along the eastern, southern, and southwestern shorelines host vegetative buffers.

Figure 2.52
Natural Shoreline Buffer



Source: Washington County Planning and Parks Department and SEWRPC

- The greatest concentration of natural shoreline was found in the northern kettle. The area is designated as a primary environment corridor (see Map 2.20) and is also a natural area of countywide and/or regional significance (see Map 2.21).

- The dominant form of shoreline protection, artificial or natural, was riprap. The only portion of the Lake's shoreline where riprap was sparse was in the northern kettle.

- Unprotected shorelines (i.e., shoreline that is mowed to the water's edge and has no vegetative or engineered shoreline protection) were scattered throughout Nagawicka Lake's shoreline area. Unprotected shorelines were most common the Lake's western channels.

- Bulkheads and revetments were uncommon forms of shoreline protection but were scattered around the entire Lake.

Given the desire of Lake users to promote long-term Lake health and the need to preserve recreational use and aesthetics of the Lake, this plan discusses application of relevant shoreline protection concepts in Chapter 3.

Bark River

Streambank Erosion

Where active streambank erosion was observed, Commission staff photographed the site and measured bank height, length of eroding bank, and depth of undercutting. Most streambanks within the surveyed reaches appeared relatively stable and well vegetated. In addition, the Bark River's channel did not appear to be excessively or unnaturally incised allowing the stream to be well-connected to adjacent floodplains. For example, average maximum streambank height was 2.3 feet, but a few locations did exceed five feet in height (see Appendix A, Table A.1).

Only about a half mile, or about 5.9 percent of the total 8.5 stream miles assessed, was visually observed to be potentially actively eroding (see Map A.1 in Appendix A). These sites occur throughout the entire length of the Bark River with the majority found within sub-basin 5. Within this sub-basin, the River passes through some of the most urbanized stretches found in the Bark River watershed upstream of Nagawicka, areas that also have a long history of human manipulation. In this stretch, the River is straighter (likely due to past channelization), is less buffered by natural vegetation due to encroachment of urban development and contains a more restricted floodplain. In contrast, the other reaches of the Bark River that contain fewer actively eroding sites are located within sub-basins 2, 4, and 6. Within these sub-basins, the Bark River contains much more extensive riparian buffers (see "Riparian Corridors" subsection for more details) and meanders to a much greater degree. A meandering stream channel, streamside vegetation, and well-connected floodplains help dissipate erosive water velocities during high flow conditions. In other words, the observed eroding stream channel reaches are likely artifacts of human manipulation. Such manipulation focuses the power inherent in flowing water in turn creating conditions fostering streambank. In these areas, erosion that will likely continue until the stream erodes the bed and banks to compensate for channel changes, further manipulation occurs to harden the banks, or until the artificial constraints placed on the stream by humans are relieved.

Since unabated erosion is likely not a viable management option, and since channel hardening is unlikely to be permitted and damages the stream ecosystem, likely intervention strategies focus on restoring natural stream function in the space now or potentially available. Stream remeandering, floodplain recreation/reconnection, nature-like slope stabilization, and bioengineering are examples of such approaches (see Chapter 3 for more details). However, it is also important to note that urbanized area contribute more runoff at a faster rate to the River, a situation increasing the River's erosive power and destabilizing formerly stable reaches. Thus, best management practices that slow the flow of water to the Bark River and reduce the runoff volume are highly desirable. Such practices include wetland restorations/riparian buffers, grassed waterways, and stormwater/green infrastructure BMPs in the urbanizing areas.

As described in section Section 2.1, "Morphology and Hydrology," the reach of the Bark River downstream of the Merton Millpond has a slope of about 0.0066 feet/feet (35 feet per mile) or lower, which is consistent with a low gradient stream condition and the field observations of limited streambank erosion. Since lateral recession rates were unknown and could not be determined, it was not possible to calculate a pollutant load rate or the overall severity from among these potentially actively eroding locations. However, there were a few sites that seemed more active than other sites and may be cause for concern as shown in Figure A.1 in Appendix A, since this sediment is potentially contributing to the degradation of instream fisheries habitat and to pollutant loads into the Bark River and Nagawicka Lake. Therefore, this is an important issue of concern and recommendations related to streambank stability are included in Chapter 3. Nevertheless, it must be remembered that sediment contributed by eroding streambanks is nearly always dwarfed by the amount of sediment delivered to streams via general upland erosion.

Artificial Streambank Protection

A total of 11 sites, all located within sub-basin 5 of the Nagawicka Lake watershed, have artificial streambank protection structures (Map A.2 in Appendix A). The protection features generally fell into three categories: wall, riprap, or sand bags (Figure 2.53). Approximately 365 feet of streambank were reinforced by walls, 285 feet were reinforced with riprap, and 280 feet were reinforced with sandbags. It is important to note that sandbag reinforcement may extend much farther. However, areas reinforced by bags were only recognizable if the bags were partially exposed. Most of the protection features were in fair to good condition. A few wall locations appear to be failing (Figure 2.54). Overall, the protection structures averaged approximately 85 feet in length and were usually one to two feet high. Photos of all artificial streambank protection features can be found in Appendix A.

Streambed Characteristics

To help characterize riverbed substrate composition, water depth, and sediment depth, 131 discrete locations were sampled along the Bark River between the Merton Millpond and Nagawicka Lake (see Map 2.27 and Appendix A). Substrate at little over half of these points was composed of mixtures of sand, gravel, and cobbles (Figure 2.55 and Map A.3 in Appendix A). Cobbles ranged from 2.5 to 10 inches in diameter. Boulders up to approximately two feet in diameter were also found at a few locations.

Bottom sediment at the remaining 47 percent of the sample points was composed of soft unconsolidated muck and silt. These fine-grained deposits were most often found where the River that widened and was flowing adjacent to wetland. The depth of soft sediment deposits averaged 1.3 feet and ranged from 0.2 feet (2.5 inches) up to 3.1 feet (Map A.4 in Appendix A). In most cases, if fine-grained sediments were less than one foot thick, the overlaid a rocky/gravelly substrate. The thickest fine-grained sediment deposits were found close to the mouth of the Bark River where it enters Nagawicka Lake (Figure 2.56). This finding is expected since River-transported bedload and some suspended sediment would be deposited in the quiescent backwater conditions near the Lake. Such sediment may be remobilized during high flow and deposited in the Lake itself.

Water depths generally increased moving downstream, as shown in Map 2.28 and Figure 2.56. In general, water depths typically measured about one to one and a half feet near Merton Dam to two to three feet ep near the Lake. However, considerable water depth variability occurs throughout the surveyed reach (e.g., shallow water in riffles versus deeper water in pool habitat). The deepest water areas were located just upstream of Nagawicka Lake. In this area, water depths up to four feet deep were measured.

Stormwater Outfalls

Stormwater outfalls discharging directly to the Bark River between the Merton Millpond and Nagawicka Lake were mapped and inspected. These outfalls are potential discrete sources of pollution and may benefit from repair, replacement, or retrofit. Twenty outfalls were found as part of this effort, with most found in sub-basin 5 (see Map A.5, Appendix A). Three were located within sub-basin 2. No stormwater outfalls were noted in sub-basins 3, 4, and 6. Most structures were in good condition with little structural cracking or noteworthy bed erosion at their point of discharge. Approximately 45 percent of the structures were constructed of corrugated steel, 30 percent were concrete, and 20 percent were plastic (Figure 2.57). Outfalls ranged in diameter from 0.5 foot to 4.0 feet (Figure 2.58). One structure (C11) was very rusted and crumbling and could potentially be replaced while another (C12) was cracked along the top (Figure 2.59). Photographs and more information on all the stormwater outfalls located during the survey can be found in Appendix A.

Although these structures generally matched the locations of outfalls provided by each MS4 community, Commission staff noted several outfalls in the Villages of Hartland and Merton that were not previously recorded and may be important to investigate or verify. These previously unidentified outfalls include six (C10 through C15) in the Village of Hartland and three outfalls (C1 through C3) in the Village of Merton. Outfall C1, located approximately 950 feet downstream of Merton Millpond and about 10 feet inland from the left (south)) bank was particularly unique because a considerable volume of water was discharging from this structure during fair weather, suggesting a groundwater source (Figure 2.60).

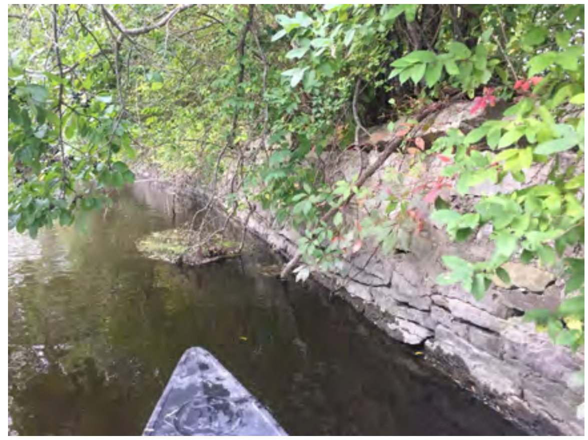
Channel Obstructions

Large woody structure such as fallen trees and branch/log accumulations was inventoried in and along the Bark River between the Merton Millpond and Nagawicka Lake during September 2016. Large woody structure can host food sources for many aquatic organisms and can provide critical cover for fish and wildlife. In addition, woody structure can help protect stream beds and banks from erosion by slowing nearshore water velocities, deflecting currents, and trapping sediment. However, excessive accumulation can impede navigation and recreational activities such as kayaking.

Over 60 areas with fallen trees were inventoried in the study reach (see Map A.6 in Appendix A for locations). The volume of material present ranged from a single tree fallen along River bank (see Figure 2.61A for an example) to multiple clusters of trees and branches along a River crossing (Figure 2.61B) to complete navigation obstruction (Figure 2.61C). Overall, 60 percent of the areas identified were a single fallen tree or a few branches collected along the River bank. These areas did not impede recreation and may have provided habitat and shelter for fish and other wildlife, and an important food source for aquatic organisms. Twenty percent of the areas identified nearly spanned the entire River channel but still did not pose a recreational blockage. The remaining twenty percent of the areas were composed of multiple fallen trees with branches, twigs, and sediment collecting amongst them. In these areas, navigation may benefit from some cleaning or log removal. However, if such debris is removed, some material should remain to protect banks from erosion and provide food and habitat.

Figure 2.53
Artificial Streambank Protection Techniques

Wall



Rip Rap

Sandbag

Source: SEWRPC

Two road/stream crossings appeared to be degraded and an abandoned bridge crossing remains (see Figures 2.62 and 2.63, respectively). In addition, three sites were identified to have significantly manipulated streambank. Riparian buffers could be re-established in these areas lessen the volume of sediment delivered to the river (see Figure 2.64).

Invasive Species

Several invasive species were observed during the Bark River inventory. Chinese (*Cipangopaludina chinensis*) and Banded (*Viviparus georgianus*) Mystery Snails were found slightly downstream of Merton Millpond (Figure 2.65). The Banded Mystery Snails were alive as indicated by their weight and their intact operculum. Only empty shells of Chinese Mystery Snails were found. Curly-leaf pondweed (*Potamogeton crispus*) was found in several locations throughout the survey reach (Figure 2.66 and Map 2.29). One plant bed, located near Rybeck Road, extended along a 1,000-foot reach of the River. Dense curly-leaf pondweed growth was also encountered within, and just downstream of, Hartland Ice Age Marsh. Finally, reed canary grass (*Phalaris arundinacea*) was frequently growing along the banks of the River (Figure 2.67). Its presence and distribution is extensive both within, and adjacent to, the Nagawicka Lake watershed. Reed canary grass infestation is a well-known problem that reduces the overall diversity and abundance of native wetland plant communities.[108]

Figure 2.54
Failing Streambank Protection Wall

Source: SEWRPC

Tires and Trash

Trash and debris degrade waterbody aesthetics and can cause physical and/or chemical (i.e., toxic) damage to aquatic and terrestrial wildlife. Commission staff mapped significant trash and debris accumulations was encountered during the September 2016 inventory. Besides the occasional grocery bag or plastic bottle, no significant accumulations of trash were visible between Merton Millpond and Nagawicka Lake. A plastic bucket, a partially buried plastic banner, and a few remnants of a child's toy were the most significant trash finds on the River (Figure 2.68).

Storm Water Conveyance and Discharge

To meet the requirements of the Federal Clean Water Act, the WDNR developed a permit Program under Wisconsin Administrative Code NR 216, "Storm Water Discharge Permits." A municipal separate storm sewer system (MS4) permit is required for a municipality that is either located within a Federally-designated urbanized area, has a population of 10,000 or more, or is designated for permit coverage by the WDNR. Municipal permits require stormwater management programs to reduce polluted stormwater runoff by implementing best management practices. Chapter NR 216 also requires certain types of industries to obtain WDNR-issued stormwater discharge permits, however, no industrial stormwater permits have been issued in the Nagawicka Lake watershed. The general permit requires a MS4 holder to develop, maintain, and implement stormwater management programs to prevent pollutants from entering State waters. Examples of stormwater best management practices used by municipalities to meet permit conditions include detention basins, street sweeping, filter strips, bioretention facilities, and rain gardens.

Waukesha County; the City of Delafield; the Villages of Hartland, Merton, Nashotah, Richfield, and Sussex; and the Towns of Delafield, Lisbon, and Merton are all designated MS4 communities in the watershed area. The Village of Chenequa is the only exempt community within the watershed, and, therefore, not subject to a MS4 Permit. These designated MS4 communities are required to reduce urban pollutants entering the local waterways via their storm sewer systems by implementing local programs. Examples of such programs include:

[108] *Distribution data for Reed Canary Grass can be found on the WDNR Surface Water Data Viewer at dnr.wi.gov/topic/surfacewater/swdv.*

Figure 2.55
Examples of Gravel and Cobble Beds in the Bark River

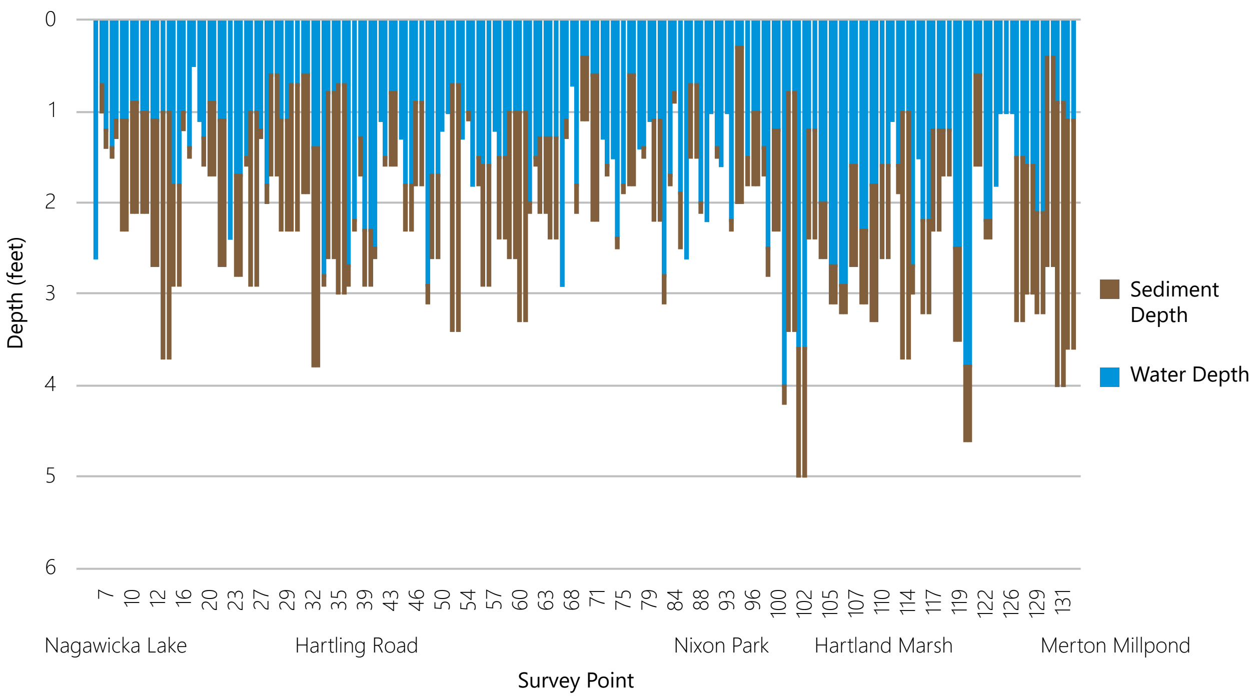
Source: SEWRPC

- Construction site and long-term stormwater control
- Illicit discharge screening
- Information and education programs regarding stormwater targeted to the general public, developers, and internal staff
- Improving municipal "good housekeeping" practices such as winter road management programs, public works yard inspections, and inventorying, mapping, and maintaining existing stormwater facilities

Each municipality must submit a report for each calendar year summarizing and evaluating the programs implemented and stating where improvements and cost-effective changes should be made.

Storm sewer system inventory information was obtained from the WDNR, Waukesha County, SEWRPC, and MS4 communities. These information sets were merged into a composite map for the entire watershed (see Map 2.30). Under their MS4 permit, each community is required to provide detailed and accurate inventories in a digital geographic information systems (GIS) software format for the following elements:

Figure 2.56
Water Depth and Flocculent Sediment Depth Conditions with the Bark River: September 2016



Source: SEWRPC

- Identify all known municipal storm sewer system outfalls discharging to waters of the State or other municipal separate storm sewer system including minor outfalls and major outfalls (36 inches in diameter or larger)[109]

- Locate and provide WPDES permit number of any known discharge to the municipal separate storm sewer system

- Locate stormwater infrastructure including facilities such as detention basins, infiltration basins, and manufactured treatment devices

- Identify publicly owned park and recreational areas and other open lands

- Locate municipal garages, storage areas and other public works facilities

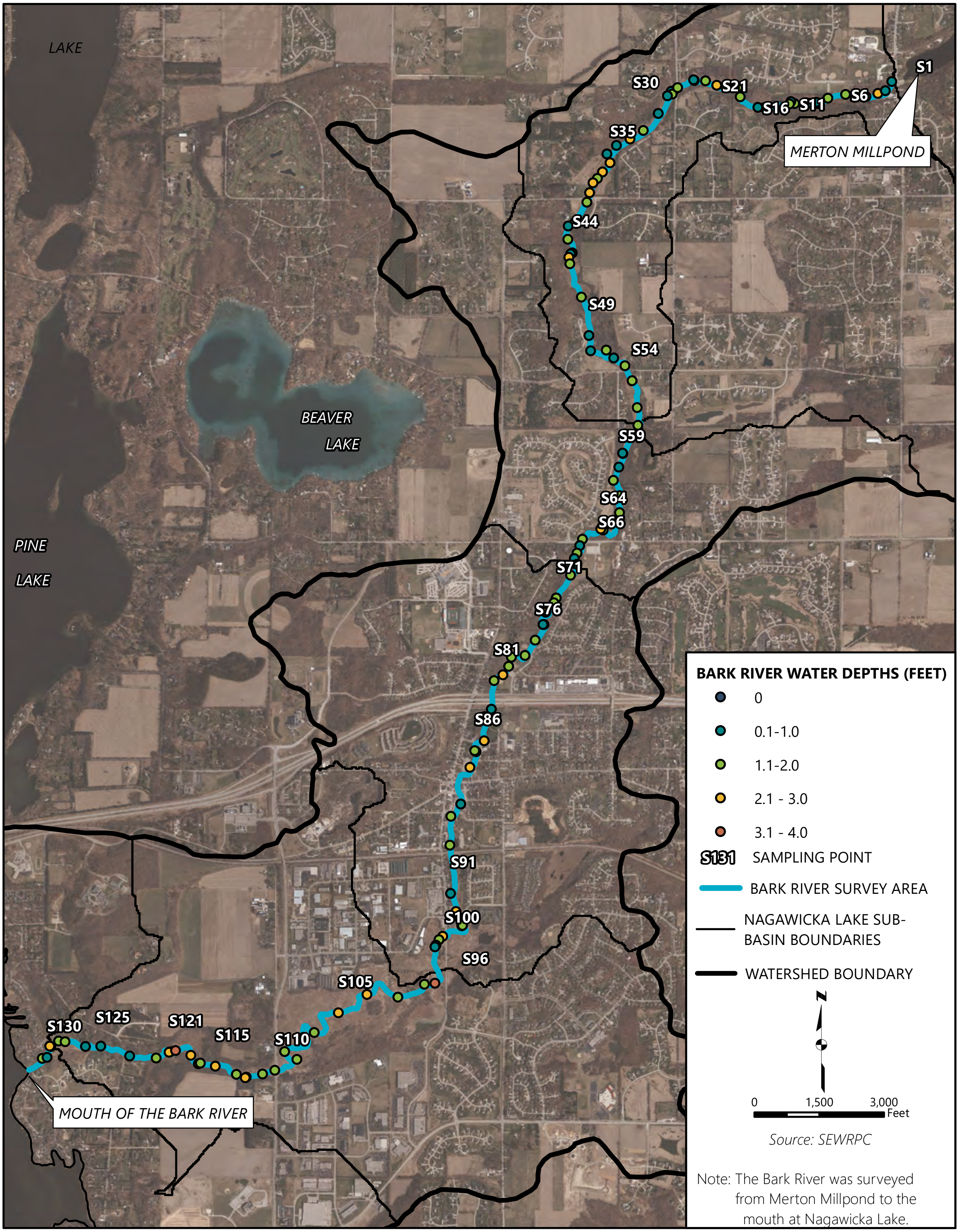
- Identify streets

Map 2.30 was developed to show stormwater information throughout the watershed as reported from 2015 through 2018. The map is not intended to show every element of the stormwater infrastructure in each community. Information on specific characteristics of municipal stormwater management systems can be located in individual reports for each community as documented in Table 2.18.

Since each of the MS4 communities compiled its inventories using different digital formats and categories, the GIS data files were integrated to the extent practicable by Waukesha County staff. The main categories include major outfalls, minor outfalls, storm sewers, swale drainage, curb and gutter, and stormwater BMPs (wet basins and dry basins) as shown on Map 2.30 and summarized in Table 2.18). Based upon this inventory data, 32 major outfalls, 284 minor outfalls, 201 dry basins, and 94 wet basins (having a permanent pond)

[109] *A major outfall is a municipal separate storm sewer outfall that meets one of the following criteria: 1) a single pipe with an inside diameter of 36 inches or more or equivalent conveyance (cross sectional area of 1,018 square inches) which is associated with a drainage area of more than 50 acres, or 2) an MS4 that receives stormwater runoff from lands zoned for industrial activity or from other lands with industrial activity that is associated with a drainage area of two acres or more.*

Map 2.28
Bark River On-The-Water Inventory: September 2016



are found within the Nagawicka Lake watershed. The storm sewers shown on Map 2.30 include both culverts and storm sewers. In addition, some communities also mapped sewer inlets, curb and gutter, and swale information, which helps better comprehend how stormwater is routed across the landscape within portions of the watershed. Most watershed storm sewer inlets are located within sub-basins 4, 5, and 6 in the Village of Hartland. Those inlets are connected to numerous minor and major outfalls that discharge directly into the Bark River (see Stream Inventory Conditions above and Appendix A). Additional outfalls are located directly adjacent to the Bark River in the Village and Town of Merton. As noted in the inventory summary section above, several of these outfalls may be good candidates for modification or improvement concepts that help reduce the quantity of stormwater-sourced sediment and pollutants entering the Bark River and, ultimately, Nagawicka Lake. Such modifications help MS4 communities meet their obligations under Wisconsin Administrative Code NR 216.

These stormwater inventory data were projected over the total extent of urban lands developed before 1990, the year stormwater rules and practices began to be widely implemented. Hence, nearly all of the stormwater BMPs are located on areas urbanized since 1990 and most areas developed before 1990 have very few structures designed to reduce stormwater runoff pollutant loads. Consequently, most of the stormwater infrastructure ringing Nagawicka Lake within sub-basins 7 through 11 and within the older portions of the Villages of Hartland and Merton consists of simple water conveyance features such as buried storm sewers, curb and gutter, and swales. It is also important to note that several minor and major outfalls discharge stormwater with limited treatment directly into Nagawicka Lake, a situation that can contribute sediment and pollutants into nearshore areas such as Zastrow Bay (see Map 2.30). Such outfalls are commonly good candidate sites for modification or improvement concepts designed to reduce the amount of sediment and pollutants delivered to the Lake.

Aside from the older portions of the Villages of Hartland and Merton, much of the urbanized area draining to the Bark River upstream of Nagawicka Lake were developed after 1990. Post-1990 development commonly include stormwater BMPs. For example, wet and dry stormwater detention basins are much more prevalent within sub-basins 1 through 6 as shown on Map 2.30 and Table 2.18. Nearly 300 of these wet and dry basins have been constructed since about 1990 and more continue to be constructed with each new development. These basins are designed to detain stormwater runoff water and release it at a rate similar to pre-development conditions. Wet basins allow bedload, suspended solids, nutrients, and associated pollutants to be to settle out. Dry basins generally provide little control of non-point source pollution but do attenuate peak flow volumes which helps attenuate erosion and flooding in downstream areas.

Figure 2.57
Example Stormwater Outfall Structures Along the Bark River

Corrugated Steel

Plastic

Concrete

Source: SEWRPC

Figure 2.58
Examples of Sizes of Outfall Structures Along the Bark River

Diameter = 0.5 Feet
Diameter = 4.0 Feet

Source: SEWRPC

Figure 2.59
Deteriorating Outfall Structures Along the Bark River

Source: SEWRPC

Urban nonpoint performance standards focus on controlling erosion through better land management. This includes carefully managing construction sites; managing post-construction runoff from parking lots, streets, buildings, and other impervious areas; promoting infiltration; maintaining vegetative buffers between impervious surfaces and water resources; and lessening the amount of pollutants carried with urban runoff. Nonpoint performance standards are implemented through county and local stormwater and erosion control ordinances for new development projects, and MS4 stormwater discharge permits for existing

Figure 2.60
Unique Outfall C-1 with Significant Discharge to Bark River

Source: SEWRPC

urban areas. Controlling construction erosion and abating non-point source pollution from urban areas relies upon targeted information and education programs for developers, engineers, contractors, municipal staff, and the general public. To this end, Waukesha County government has executed intergovernmental agreements with each MS4 municipality located in the Waukesha County portion of the Nagawicka Lake watershed. The intergovernmental agreements allow Waukesha County to implement a comprehensive stormwater education program to help communities meet this part of the MS4 permit mandate. The county agreements with the Village of Merton and the Towns of Delafield, Lisbon, and Merton includes provisions for enforcement. The Village of Richfield, located within the headwaters of the watershed within Washington County, is handling its own information and educational outreach programs. Care should be taken to coordinate informational and educational programing throughout the watershed.

Riparian Corridors

General Principles and Watershed Conditions

Healthy riparian corridors help protect water quality, groundwater, fisheries, wildlife, ecological resilience to invasive species and climate change, and can reduce the severity of flood events.[110] The health of riparian corridors is largely dependent upon its width and lateral/longitudinal continuity. Therefore, efforts to protect, connect, and restore remaining riparian corridor width and continuity are foundational to protect and improve the fishery, wildlife, recreational value, ecological resilience, and flood protection value of the Nagawicka Lake watershed.

Providing buffer strips along waterways helps mitigate the increased amount of sediment, nutrients, and contaminants introduced to waterbodies by human activity. Even relatively narrow buffer strips can provide substantial benefit, as suggested in Table 2.19 and Figure 2.69 and further discussed in Appendix B.[111] The Wisconsin Buffer Initiative (WBI) developed two key concepts relevant to this plan: 1) riparian buffers are very effective in protecting water resources and 2) riparian buffers need to be integral to larger conservation system to be most effective.[112]

[110] *N.E. Seavy, et al., "Why Climate Change Make Riparian Restoration More Important than Ever: Recommendations for Practice and Research,"* Ecological Restoration *27(3): 330-338, 2009;* "Association of State Floodplain Managers, Natural and Beneficial Floodplain Functions: Floodplain Management—More Than Flood Loss Reduction, 2008," *s3-us-west-2.amazonaws.com/asfpm-library/FSC/General/ASFPM_Natural_Floodplain_Functions_2008.pdf.*

[111] *Data were drawn from A. Desbonnet, P. Pogue, V. Lee, and N. Wolff, "Vegetated Buffers in the Coastal Zone – A Summary Review and Bibliography,"* CRC Technical Report No. 2064*, Coastal Resources Center, University of Rhode Island, 1994.*

[112] *University of Wisconsin-Madison, College of Agricultural and Life Sciences,* The Wisconsin Buffer Initiative*, December 2005.*

Figure 2.61
Fallen Trees Along the Bark River

(A) Single Trees or Branches

(B) Slight Accumulation or Blockage

(C) Navigation Completely Blocked

Source: SEWRPC

Figure 2.62
Deteriorating Bark River Crossing at Dorn Road

West East

Source: SEWRPC

One must note that the WBI limited its assessment and recommendations solely to protecting water quality and did not consider the additional values and benefits that riparian buffers provide. Research clearly shows that riparian buffers may yield a diverse variety of benefits including mitigating floods, preventing channel erosion, providing of fish and wildlife habitat, enhancing environmental corridors, and moderating water temperature (see Appendix B). However, the exact nature of such benefits and the extent to which the benefits are achieved is extremely site-specific. Consequently, suggested buffer width ranges for each buffer functions are large (see Figure 2.69). Therefore, buffer widths must be grounded not only on desired functions, but also by considering specific site conditions. For example, based upon a number of sediment removal studies, buffer r ranging from about 25 to nearly 200 feet wide removed between 33 and 92 percent of sediment carried by runoff. Removal efficiencies varied with differences in local site-specific such as soil type, slope, vegetation, contributing area, and influent concentrations, to name a few. Figure 2.69 shows that for any particular buffer width (for example 75 feet) the buffer can provide multiple benefits, ranging from moderating water temperature to enhancing wildlife species diversity. An example of a benefits not shown in the figure include bank stabilization, which is an important reason to utilize buffers for habitat protection (see Appendix B).

While it is clear from the literature that wider buffers generally provide a greater range of positive values for aquatic systems, the need to balance human needs and desires with environmental benefits suggests that a 75-foot-wide riparian buffer is the minimum width necessary to improve water quality and a promote a healthy aquatic ecosystem. In general, most pollutants are removed within a 75-foot buffer width. However, 75-foot-wide buffers are often inadequate to protect the full spectrum of ecological services riparian buffers can provide. Riparian buffer strips greater than 75 feet in width provide significant additional physical protection to waterbodies. For example, wider buffers also help sustain groundwater recharge and discharge relationships and provide the space needed by wildlife to complete life-cycle critical functions.[113]

As a testament to the value of buffers, the highest quality environmental corridors, natural areas, and vegetation communities are located within and adjacent to the riparian buffer network throughout the Nagawicka Lake watershed (see Map 2.31). In other words, riparian buffers are a vital conservation tool that provides landscape-scale connectivity which in turn improves viability of wildlife populations within primary and secondary environmental corridors and isolated natural resource areas.[114]

[113] *See, for example, B.M. Weigel, E.E. Emmons, J.S. Stewart, and R. Bannerman, "Buffer Width and Continuity for Preserving Stream Health in Agricultural Landscapes,"* Wisconsin Department of Natural Resources Research and Management Findings*, Issue 56, 2005.*

[114] *P. Beier and R.F. Noss, "Do Habitat Corridors Provide Connectivity?,"* Conservation Biology *12(6), 1998.*

Physically broad, ecologically diverse, continuous riparian buffers help sustain healthy aquatic and terrestrial wildlife populations. Specifically, recent research finds that wildlife species protection is determined by the preservation or protection of core habitat within riparian buffers with widths ranging from a minimum of 400 feet to an optimal 900 feet or greater as summarized in Appendix B. These buffer areas are essential for supporting healthy populations of multiple groups of organisms, including birds, amphibians, mammals, reptiles, and insects and their various life stages. For example, some species of birds, amphibians, turtles, snakes, and frogs have been found to need buffer widths as great as 2,300 feet, 1,500 feet, 3,700 feet, 2,300 feet, and 1,900 feet, respectively, for at least part of their life histories. Hence, preservation of riparian buffers to widths of up to 1,000 feet or greater represents the optimal condition for the protecting wildlife in most watersheds.[115]

Figure 2.63
Remnants of Former Ice Age Trail Bridge

Source: SEWRPC

Map 2.31 shows the major natural cover types both within and outside of existing riparian buffers throughout the Nagawicka Lake watershed. This inventory shows that the Watershed's riparian buffers are comprised of a variety of wetland (emergent/wet meadow, flats, forested, and scrub/shrub) and upland (brush, grassland, upland conifer, and deciduous) vegetative communities. Each habitat type supports critical life history requirements of multiple wildlife species. For example, amphibians and reptiles have been reported to utilize numerous habitat types that include seasonal (ephemeral) wetlands, permanent wetlands (lakes, ponds, and marshes), wet meadows, bogs, fens, small and large streams, springs and seeps, hardwood forest, coniferous forest, woodlands, savannahs, grasslands, and prairies.[116] Hence, this habitat mosaic and the ability of organisms to travel between them at the correct times in their lives to survive, grow, and reproduce, is essential to support an abundant and diverse wildlife community throughout this watershed.

Human development patterns and infrastructure often create obstructions that can limit both the availability of wildlife habitat and the ability for organisms to travel between habitat areas. These obstructions include roadways, railways, and buildings that fragment the natural landscape. Therefore, an effective management strategy to protect wildlife abundance and diversity in the Nagawicka Lake watershed would be to secure critical linkages between habitat areas on the landscape, ensuring the ability of species to access these areas. Examples of critical linkages include the following:

- Water's edge (lake, pond, river, wetland) to terrestrial landscapes (i.e., riparian buffer width)
- Water's edge to water's edge (e.g., river to ephemeral pond, lake to ephemeral pond, permanent pond to ephemeral pond)
- Habitat complexes or embedded habitats (e.g., wetland to upland (e.g., seep to prairie) and upland to upland (e.g., grassland to woodland))

[115] *The shoreland zone is defined as extending 1,000 feet from the ordinary high-water mark of lakes, ponds, and flowages and 300 feet from the ordinary high-water mark of navigable streams, or to the outer limit of the floodplain, whichever is greater. To be consistent with this concept and to avoid confusion, the optimum buffer width for wildlife protection is defined as extending 1,000 feet from the ordinary high-water mark on both sides of the lakes, ponds, and navigable streams in the watershed.*

[116] *B.A. Kingsbury and J. Gibson (editors),* Habitat Management Guidelines for Amphibians and Reptiles of the Midwestern United States, *Partners in Amphibian and Reptile Conservation Technical Publication HMG-1. 2nd Edition, 155 pages, 2012.*

Figure 2.64
Examples of Areas that Would Benefit from Improved Buffers

Immediately South of Highway 16

Immediately South of Park Avenue

Immediately South of Highway 16

Source: SEWRPC

Figure 2.65
Chinese and Banded Mystery Snails Found in the Bark River

Chinese Mystery Snail Banded Mystery Snail

Source: SEWRPC

Figure 2.66
Curly-Leaf Pondweed Found in the Bark River

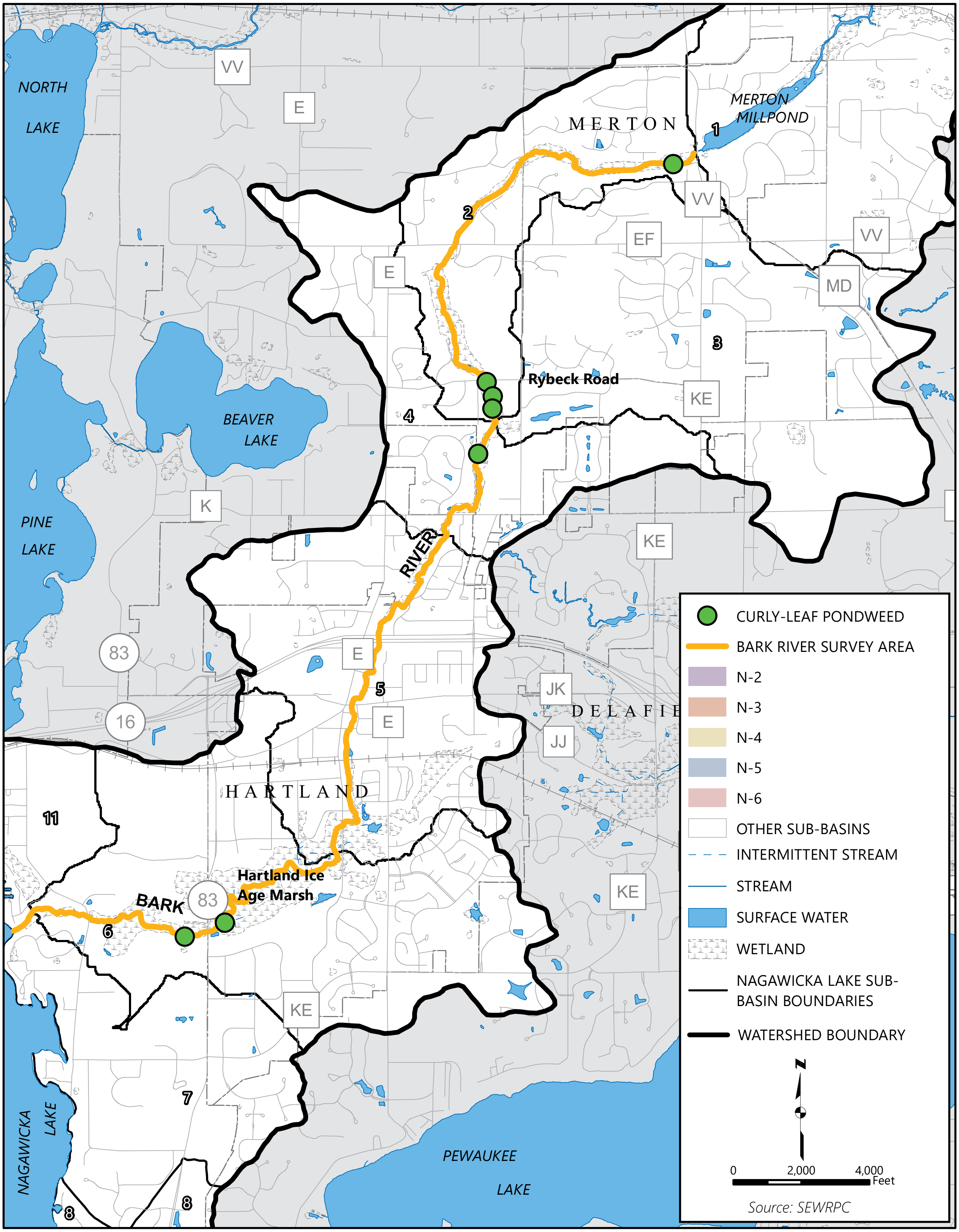
Source: SEWRPC

A sound approach to achieve this goal would be endeavoring to connect and expand environmental corridors and natural areas throughout the watershed. An example of a very basic approach would be providing naturalized, passive use, or semi-natural corridors connecting secondary environmental corridor (SEC) lands and multiple isolated natural resource areas (INRAs) with primary environmental corridor (PEC) areas. Any action that helps relieve human constraints upon the natural environment can benefit such an initiative and does not necessitate the complete exclusion of human land use needs and desires. Such initiatives can range from providing wildlife access paths that do not require hazardous road crossings, being cognizant of the effect fences can have on wildlife migration, maintaining areas as park or cropland use, controlling invasive species and promoting natural plant communities, and de-emphasizing the role of lawns and pesticides in residential landscaping.

Potential Restorable Wetlands

Wetlands provide many benefits including water quality improvement, wildlife habitat, and flood mitigation. For example, according to the USEPA, a typical one-acre wetland can store about one million

Map 2.29
Locations Where Curly-Leaf Pondweed was Detected: September 2016



gallons of water.[117] Restoring wetlands can increase a watershed's floodwater storage capacity and reduces sediment and phosphorus loading to lakes and streams Establishing restored wetlands, particularly as riparian buffers (see "Riparian Corridors" subsection), can help reduce pollution loads from tile drains, impervious areas, barnyards, and upland runoff, and can often be implemented in flood-prone marginally productive areas where high water frequently damages crops. Although modeling load reductions associated with wetland restorations is beyond the scope of this report, constructed wetlands have been reported to reduce median pollutant loads by 73 percent for total suspended solids, 38 percent for total phosphorus, 69 percent for particulate phosphorus, 30 percent for total nitrogen, 70 percent for metals (zinc and copper), 60 percent for bacteria, and, 80 percent for hydrocarbons.[118]

Figure 2.67
Reed Canary Grass Found on the Banks of the Bark River

Source: SEWRPC

Hydric soils (a characteristic of wetland conditions) form under settings where soil is saturated long enough to changes soil properties. The unique conditions of these soils foster a suite of plant species that thrive in wet, oxygen-deprived soil. Most wetlands remaining in the Nagawicka Lake watershed are found along the Bark River and its tributaries. Wetlands currently cover 10.6 percent of the Nagawicka Lake watershed. This meets a standard established by Environment Canada for the minimum recommended level of wetland area needed to protect a major watershed, but this minimum also includes meeting a level of six percent wetland for each subwatershed.[119] Although six of the sub-basins (namely, 1, 2, 6, 5, 9, and 11) meet or exceed the recommended minimum level of six percent criteria for subwatershed areas, the remaining five sub-basins do not. In particular, sub-basin 4 contains about 2.7 percent wetland, sub-basin 10 contains 1.2 percent wetland, and sub-basins 3, 7, 8 each contain less than one percent wetland. There is a good potential to restore wetlands throughout the Nagawicka Lake watershed, which could be a key component to addressing non-point source soil erosion and associated pollutant load reduction.

Based on information from the WDNR "potentially restorable wetlands (PRW)" geographic information system layer, approximately 439 acres of potentially restorable wetland are found in the Nagawicka Lake watershed (see Map 2.30). Sub-basin 1 contains 313 acres of PRW, which is more than twice the amount of PRW in all the other sub-basins combined. Sub-basins 9 and 2 each contain the next highest areas of PRW with 50 acres and 27 acres, respectively. Collectively, sub-basins 4, 5, 6, 7, 10, and 11 comprise the remaining 49 acres of PRW. Sub-basins 3 and 8 do not contain any PRW.

Potentially restorable wetland areas are good candidate sites for constructed floodplain benches associated with remeandering ditched reaches and/or provide opportunities to modify tile drainage to reduce pollutant loads delivered to surface water. Therefore, any PRW areas located within the existing floodplain boundary should be a high priority for wetland restoration. Onsite evaluation of potential wetland restoration sites will be necessary to evaluate each site's unique limitations and values. Potential restoration sites should be prioritized to assure the most beneficial projects are pursued.

[117] *U.S. Environmental Protection Agency (USEPA),* Wetlands: Protecting Life and Property from Flooding*, May 2006, USEPA843-F-06-001, water.epa.gov/type/wetlands/outreach/upload/Flooding.pdf.*

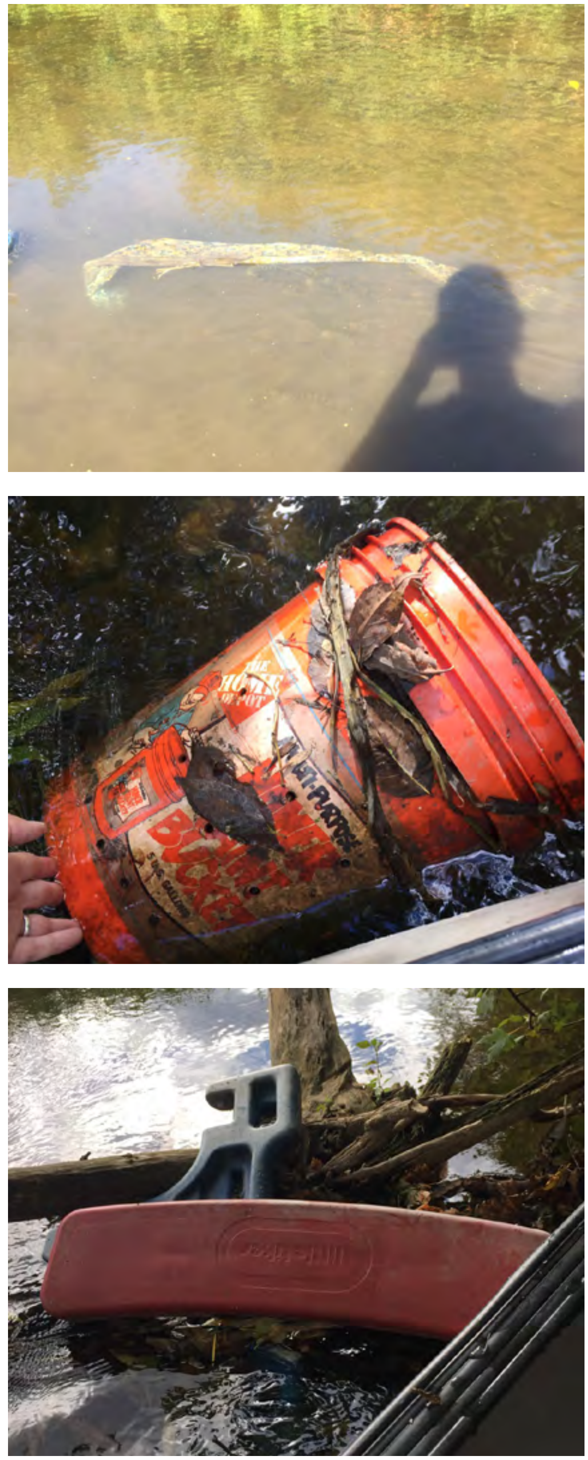
[118] *Minnesota Pollution Control Agency, Minnesota Stormwater Manual website, stormwater.pca.state.mn.us/index.php/Information_on_pollutant_removal_by_BMPs.*

[119] *Environment Canada, 2013,* How Much Habitat is Enough*? Third edition, Environment Canada, Toronto, Ontario, www.documentcloud.org/documents/2999368-THUNDER-BAY-How-Much-Habitat-Is-Enough-3rd-Ed-2013.html.*

Existing and Potential Riparian Buffers

Map 2.32 compares the extent of existing riparian buffers, suggested buffer widths of 75, 400, and 1,000-feet, and potentially restorable wetland areas along the Bark River and its major tributary streams. Buffers on Map 2.32 were developed from 2015 digital orthophotography, the 2010 WDNR Wisconsin Wetland Inventory, and from the Commission's inventories of PECs, SECs, and INRAs. Polygons were created using geographic information system (GIS) techniques to delineate contiguous natural lands (i.e., nonurban and nonagricultural lands) comprised of wetland, woodland, and other open lands adjacent to waterbodies. Those lands comprise 5,491 acres, or 19.1 percent, of the total land area (not including water area) within the Nagawicka Lake watershed.

Figure 2.68
Trash Found During the September 2016 Bark River Survey



Source: SEWRPC

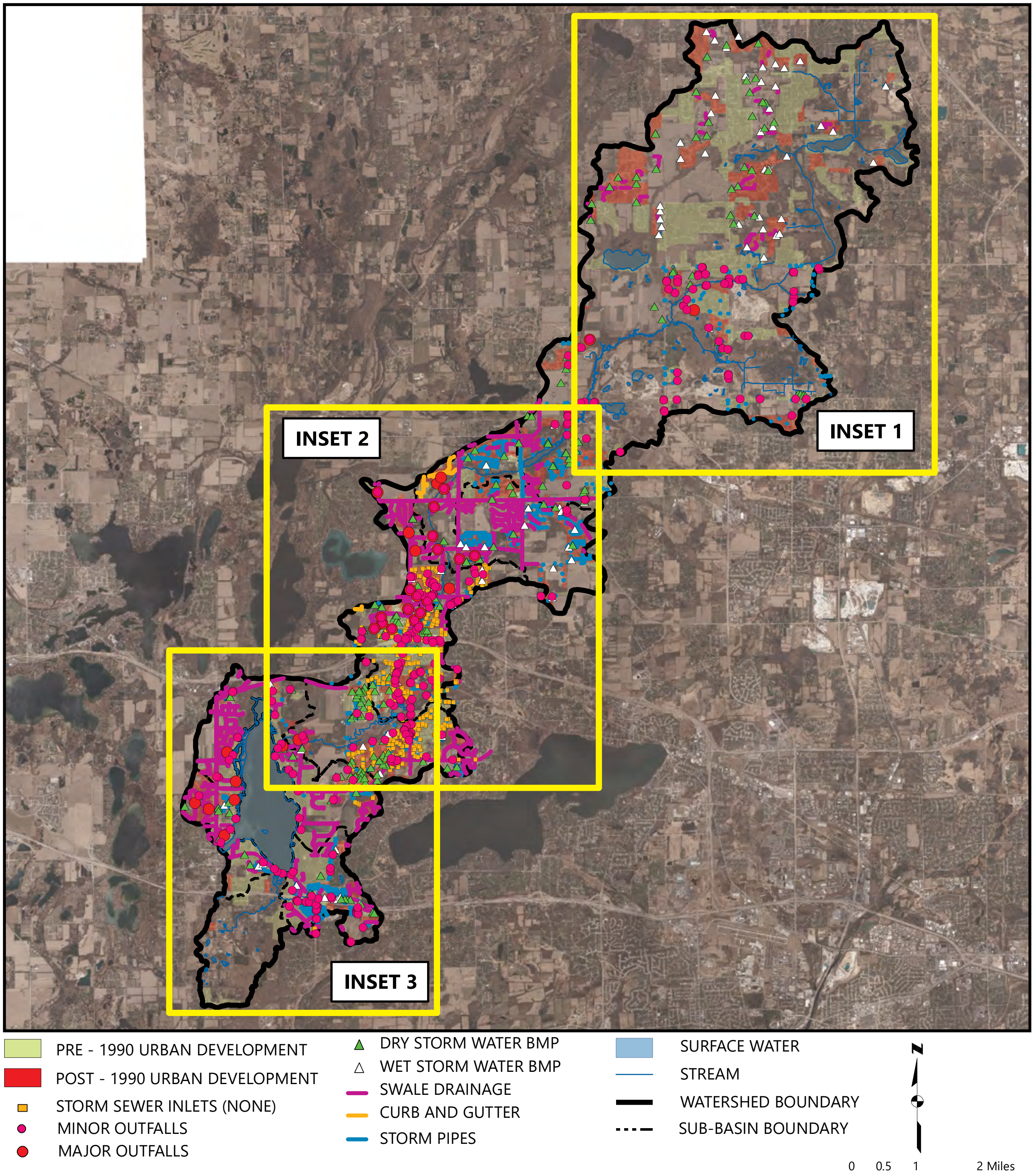
As shown on Map 2.32 and Figure 2.70, the most extensive existing buffers were found within sub-basins 1, 2, 3, 6, 9, and 11 that together comprised about 92 percent (5,044 acres) of the total buffered lands within the Nagawicka Lake watershed. Existing buffers comprise 13 to 59 percent of the total land area within these sub-basins (Figure 2.71). In contrast, the remaining five sub-basins 4, 5, 7, 8, and 10 contain only 8 percent (447 acres) of the total buffered lands within the watershed that ranged from a total of 3 to 11 percent of existing buffers of the total land area within each of their respective sub-basins.

Comparing existing buffers to potential buffers at the 75-foot, 400-foot, and 1,000-foot widths throughout the Nagawicka Lake watershed reveals that existing buffers provide significant levels of protection at the 75-foot, 400-foot, and some areas whose widths exceed 1,000 feet from the edge of the stream. This finding reveals that existing buffers already provide a good level of water quality and wildlife protection (see Map 2.32). In addition, roughly 75 percent of Bark River watershed streambanks are protected by buffers of at least 75-feet wide, which is the minimum width for water quality protection (see Appendix B).

Even though much of the streambank length of the Bark River watershed benefits from buffers, multiple locations in both urban and agricultural areas throughout the watershed are not well buffered (see Map 2.32). Significant encroachments into the 75-foot riparian buffer zone are found within sub-basins 1, 4, 5, 7, 8, 10, 11 which includes the Nagawicka Lake shoreline. It is important to note that there are about 8.1 linear miles (42,987 feet) of non-buffered riparian shoreline are found around the perimeter of Nagawicka Lake. That distance represents 48 percent of the Lake's total shoreline length.

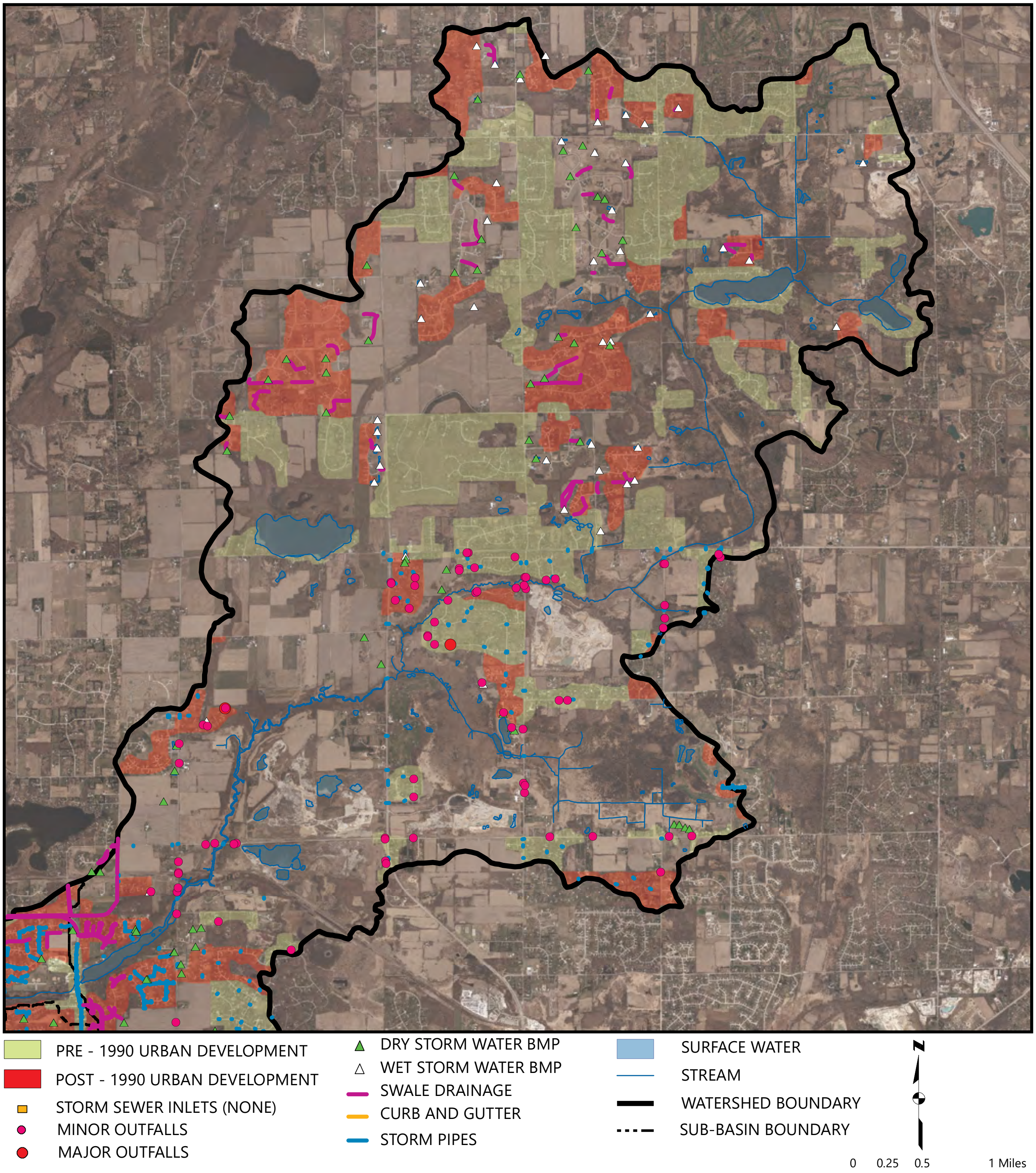
Based upon our inventory findings, many opportunities exist to improve riparian buffers (at the 75-foot, 400-foot, and 1,000-foot widths) both within the Bark River network and the Nagawicka Lake shoreline (see Map 2.32 and Figure 2.71). Those opportunities will be discussed in more detail in Chapter 3.

Map 2.30
Stormwater Drainage Systems Within the Nagawicka Lake Watershed: 2018



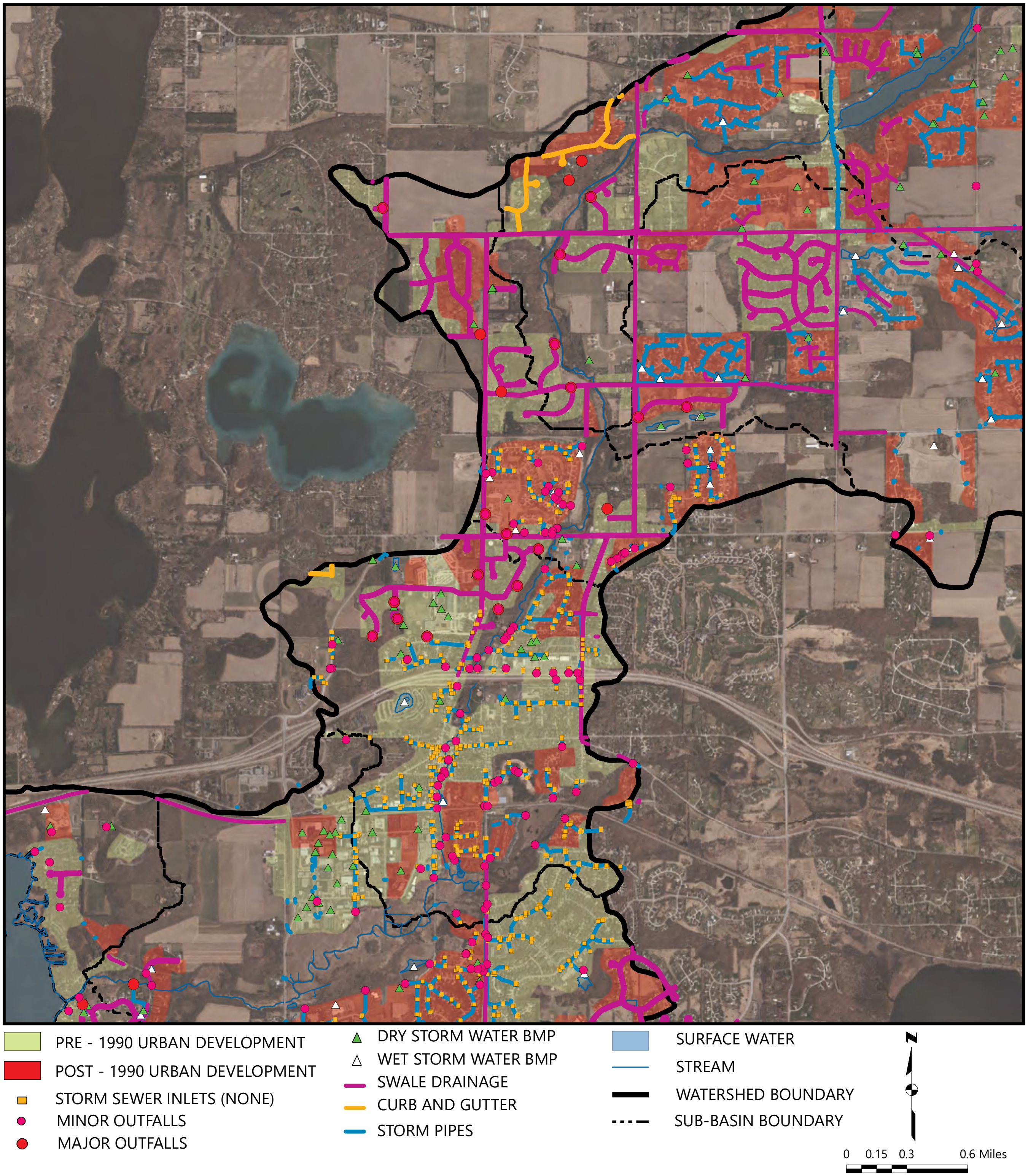
Source: City of Delafield, SEH; Town of Delafield, R.A.Smith National, Inc.; Town of Lisbon, Strand Associates, Inc.; Town of Merton, SEH; Village of Hartland, Ruekert | Meilke, Inc.; Village of Merton, SEH; Village of Nashotah, R.A. Smith National, Inc.; Village of Richfield, Kunkel Engineering Group; Village of Sussex, Ruekert | Mielke, Inc., Waukesha County, and SEWRPC

Map 2.30 (Inset 1)
Stormwater Drainage Systems Within the Northern Portion of the Nagawicka Lake Watershed: 2018



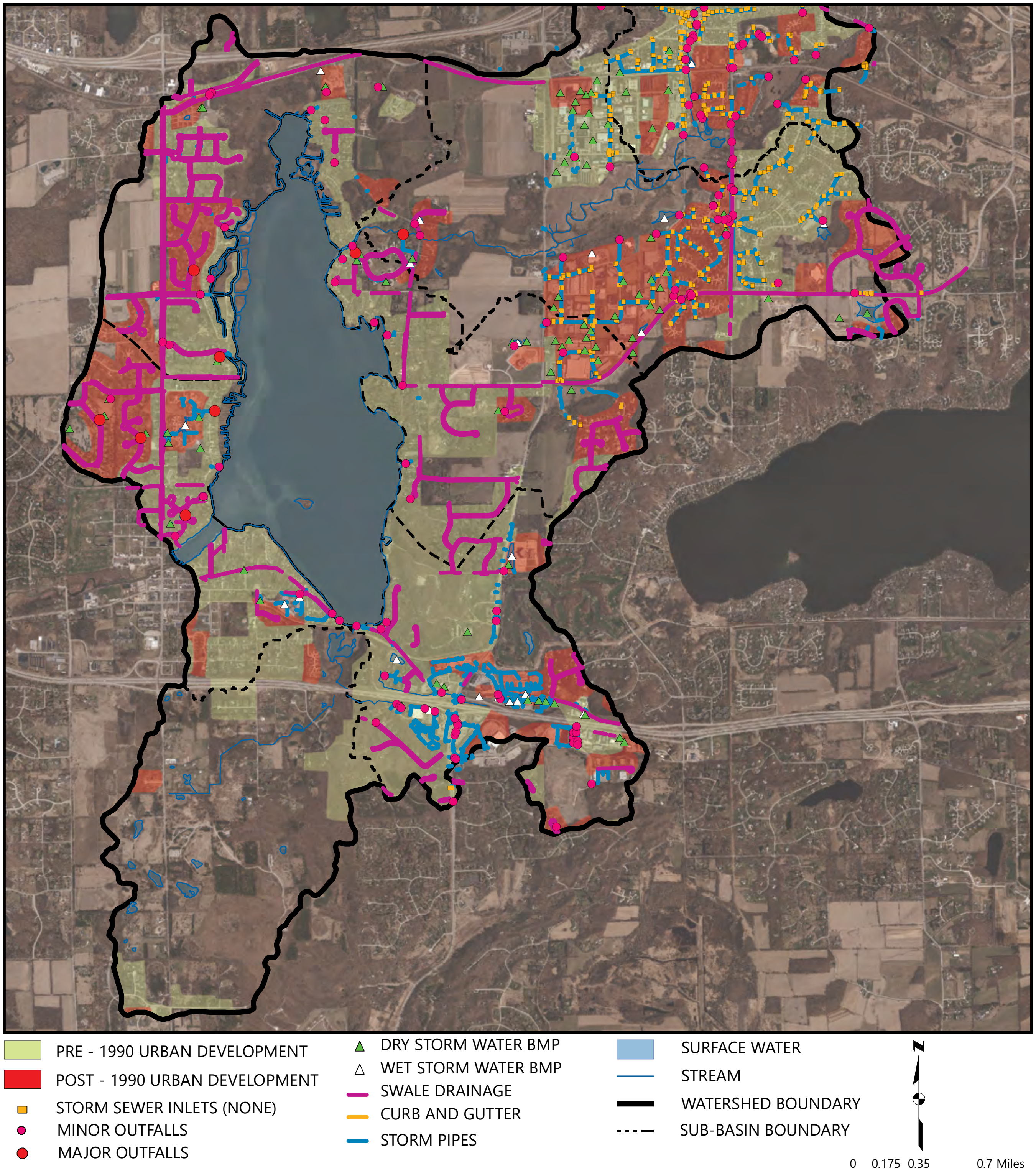
Source: City of Delafield, SEH; Town of Delafield, R.A.Smith National, Inc.; Town of Lisbon, Strand Associates, Inc.; Town of Merton, SEH; Village of Hartland, Ruekert | Meilke, Inc.; Village of Merton, SEH; Village of Nashotah, R.A. Smith National, Inc.; Village of Richfield, Kunkel Engineering Group; Village of Sussex, Ruekert | Mielke, Inc., Waukesha County, and SEWRPC

Map 2.30 (Inset 2)
Stormwater Drainage Systems Within the Middle Portion of the Nagawicka Lake Watershed: 2018



Source: City of Delafield, SEH; Town of Delafield, R.A.Smith National, Inc.; Town of Lisbon, Strand Associates, Inc.; Town of Merton, SEH; Village of Hartland, Ruekert | Meilke, Inc.; Village of Merton, SEH; Village of Nashotah, R.A. Smith National, Inc.; Village of Richfield, Kunkel Engineering Group; Village of Sussex, Ruekert | Mielke, Inc., Waukesha County, and SEWRPC

Map 2.30 (Inset 3)
Stormwater Drainage Systems Within the Southern Portion of the Nagawicka Lake Watershed: 2018



Source: City of Delafield, SEH; Town of Delafield, R.A.Smith National, Inc.; Town of Lisbon, Strand Associates, Inc.; Town of Merton, SEH; Village of Hartland, Ruekert | Meilke, Inc.; Village of Merton, SEH; Village of Nashotah, R.A. Smith National, Inc.; Village of Richfield, Kunkel Engineering Group; Village of Sussex, Ruekert | Mielke, Inc., Waukesha County, and SEWRPC

Table 2.18
Nagawicka Lake Watershed MS4 Community Stormwater Infrastructure Inventory: 2019

	Stormwater Management System Category				
		Outfalls		Best Management Practices (BMP)	
Sub-Basin	Sewer Inlets	Minor	Major	Dry Basin	Wet Basin
1	0	74	2	68	44
2	0	4	6	4	1
3	0	5	2	10	14
4	118	34	7	11	11
5	476	66	7	26	2
6	289	32	1	35	7
7	42	12	1	17	1
8	5	34	0	13	10
9	0	3	0	0	0
10	0	6	4	12	3
11	1	14	2	5	1
Total	931	284	32	201	94

Source: Source: City of Delafield, SEH; Town of Delafield, R.A. Smith National, Inc.; Town of Lisbon, Strand Associates, Inc.; Town of Merton, SEH; Village of Hartland, Ruekert|Mielke, Inc.; Village of Merton, SEH; Village of Nashotah, R.A. Smith National, Inc.; Village of Richfield, Kunkel Engineering Group; Village of Sussex, Ruekert|Mielke, Inc.; Waukesha County PLU - Land Resources Division; and SEWRPC

Table 2.19
Buffer Width's Influence on Contaminant Removal Efficiency

	Contaminant Removal (percent)[a]				
Buffer Width Categories (feet)	Sediment	Total Suspended Sediment	Nitrogen	Phosphorus	Nitrate-Nitrogen
1.5 to 25					
Mean	75	66	55	48	27
Range	37-91	31-87	0-95	2-99	0-68
Number of Studies	7	4	7	10	5
25 to 50					
Mean	78	65	48	49	23
Range	--	27-95	7-96	6-99	4-46
Number of Studies	1	6	10	10	4
50 to 75					
Mean	51	--	79	49	60
Range	45-90	--	62-97	0-99	--
Number of Studies	5	--	2	2	1
Greater than 75					
Mean	89	73	80	75	62
Range	55-99	23-97	31-99	29-99	--
Number of Studies	6	9	8	7	1

[a] *The percent contaminant reductions in this table are limited to surface runoff concentrations.*

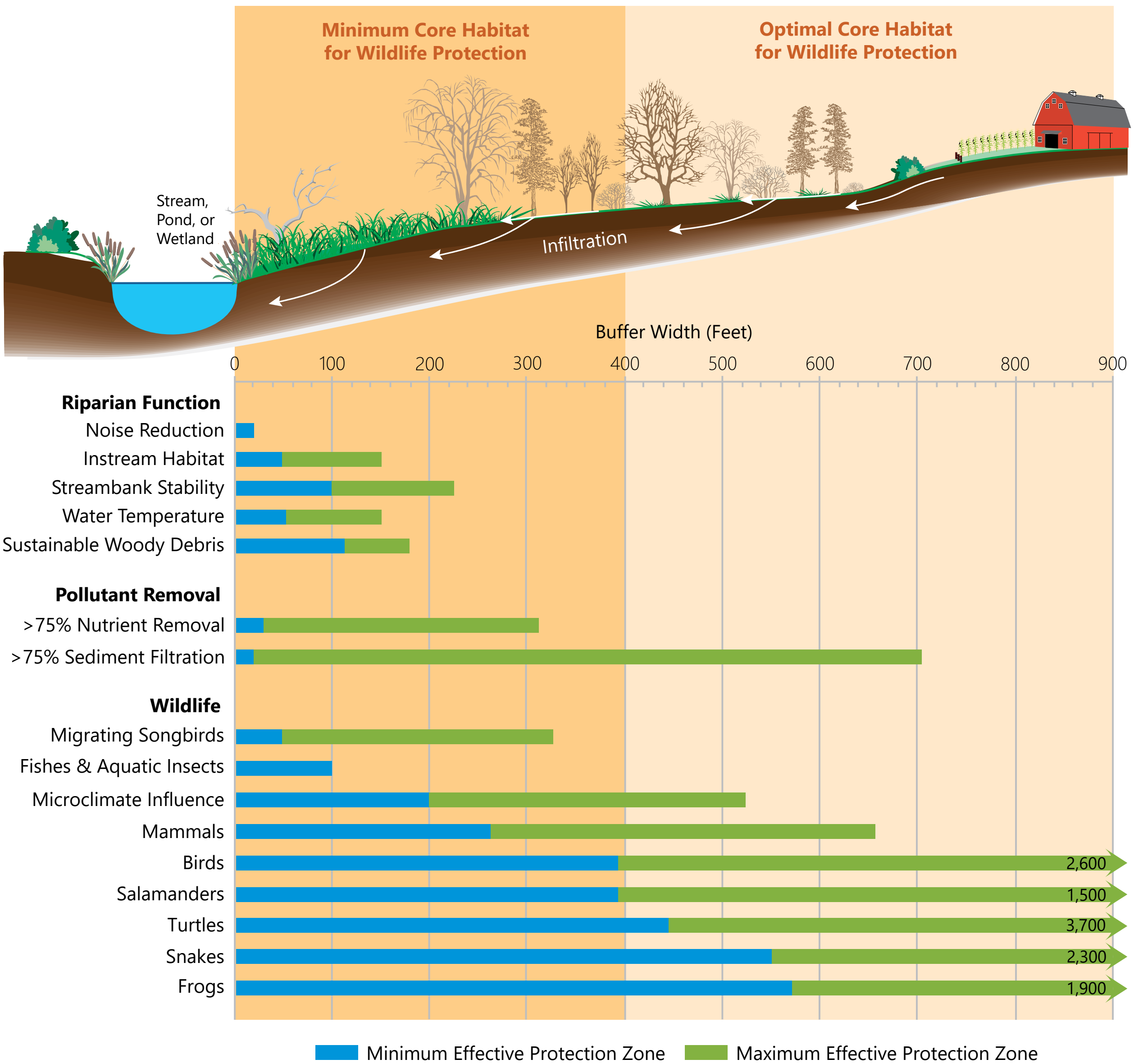
Source: University of Rhode Island Sea Grant Program

Riparian Buffer Protection and Prioritization Strategies

All riparian buffers provide some level of protection that is greater than if there were no buffer at all. However, wider buffers provide a greater number of functions (infiltration, temperature moderation, and species diversity) than narrower buffers. Therefore, it is important that existing buffers be protected and expanded where possible.

The riparian buffer network out to the 75-foot, 400-foot, and 1,000-foot widths as discussed in the preceding subsection provides a framework upon which to protect and improve water quality and wildlife within the Nagawicka Lake watershed. This framework can be achieved through a combination of strategies that include land acquisition, regulation, and best management practices.

Figure 2.69
Range of Buffer Widths for Providing Specific Buffer Functions



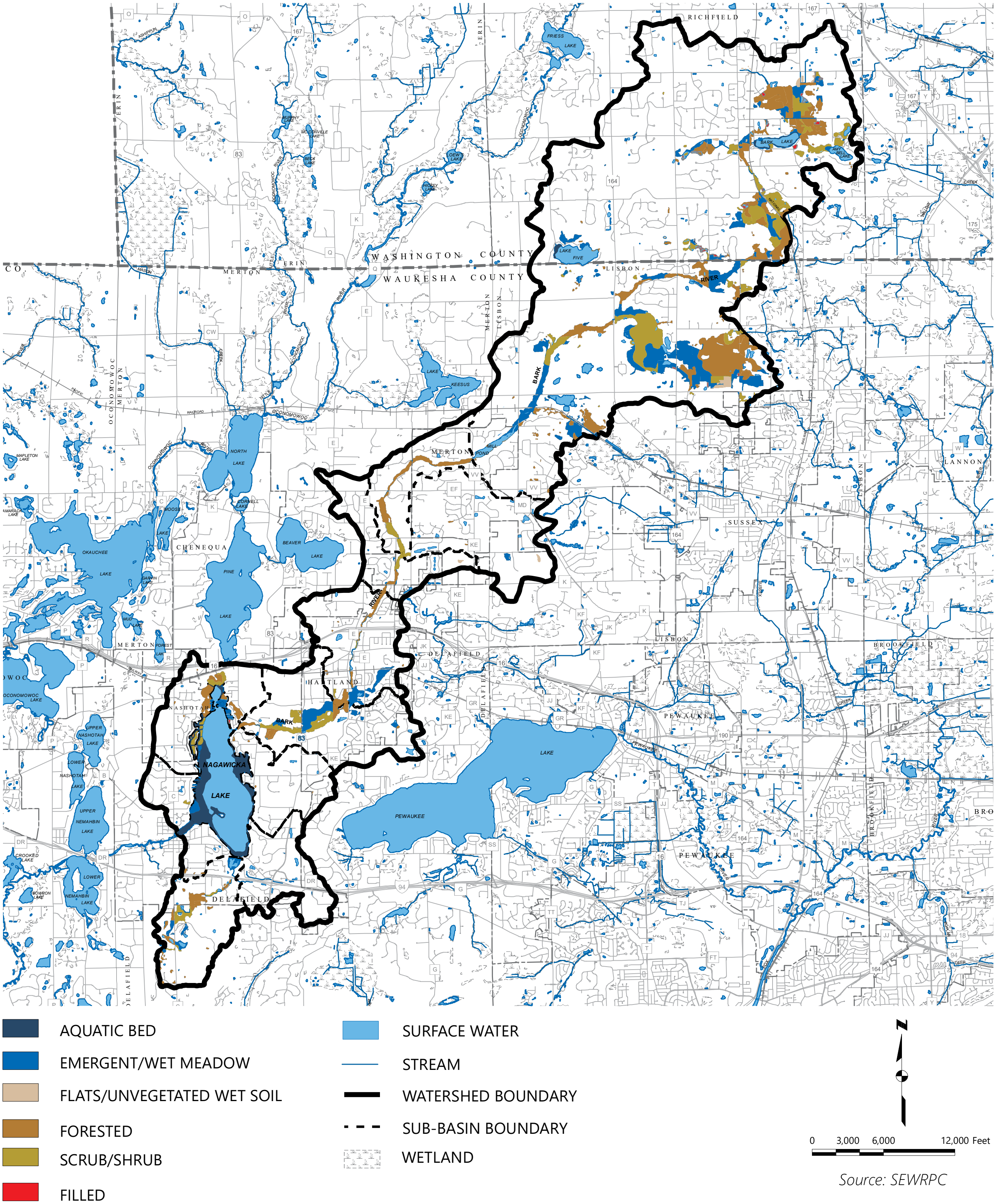
Source: SEWRPC

Land Acquisition or Permanent Easements

Prioritizing suitable land (including PEC, SEC, and INRA, and natural areas (NAs)) acquisition should consider the following factors. The most important factors are listed first.

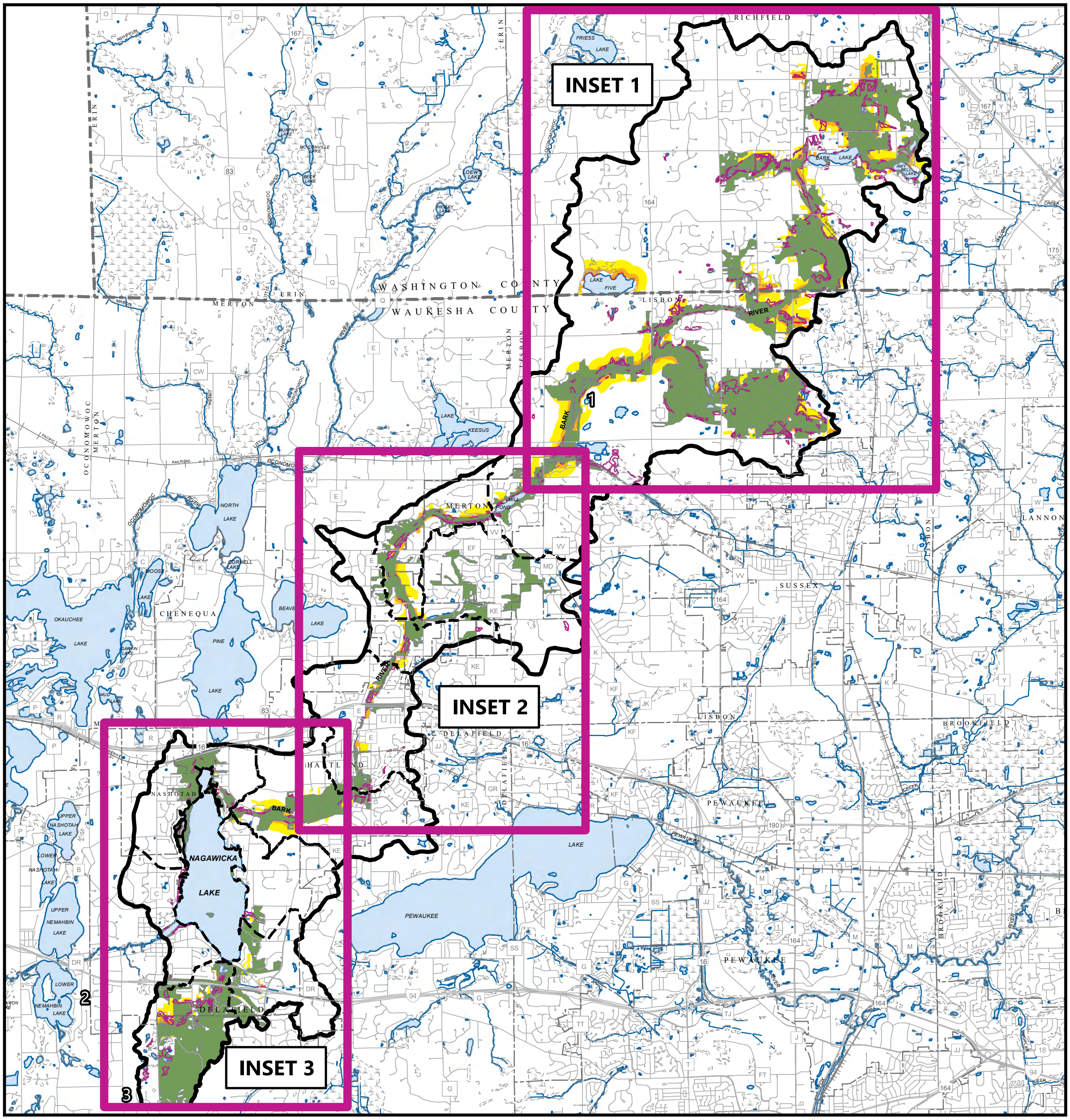
1. Land that is existing riparian buffer (protect what exists on the landscape)
2. Land that is potential riparian buffer lands up to 75 feet wide (minimum level of protection for pollutants)
3. Land occupied by potentially restorable wetland within 1,000 feet of Nagawicka Lake, the Bark River, or tributaries (see Map 2.32) or the 1-percent-annual-probability-floodplain (see Map 2.15), whichever is greater (priority for pollutant removal and wildlife habitat protection)
4. Lands that are potential riparian buffer lands up to 400 feet wide (minimum wildlife protection)
5. Lands that are potential riparian buffer lands up to 1,000 feet wide (optimum wildlife protection)

Map 2.31
Wetland Categories in the Nagawicka Lake Watershed: 2010



Source: SEWRPC

Map 2.32
Existing and Potential Riparian Buffers Within the Nagawicka Lake Watershed: 2015



EXISTING AND POTENTIAL RIPARIAN BUFFER

EXISTING RIPARIAN BUFFER

75 FEET: MINIMUM RECOMMENDED BUFFER WIDTH

400 FEET: MINIMUM CORE HABITAT WIDTH FOR WILDLIFE PROTECTION

1000 FEET: OPTIMAL CORE HABITAT WIDTH FOR WILDLIFE PROTECTION

SURFACE WATER

STREAM

WATERSHED BOUNDARY

SUB-BASIN BOUNDARY

POTENTIAL RESTORABLE WETLAND

WETLAND

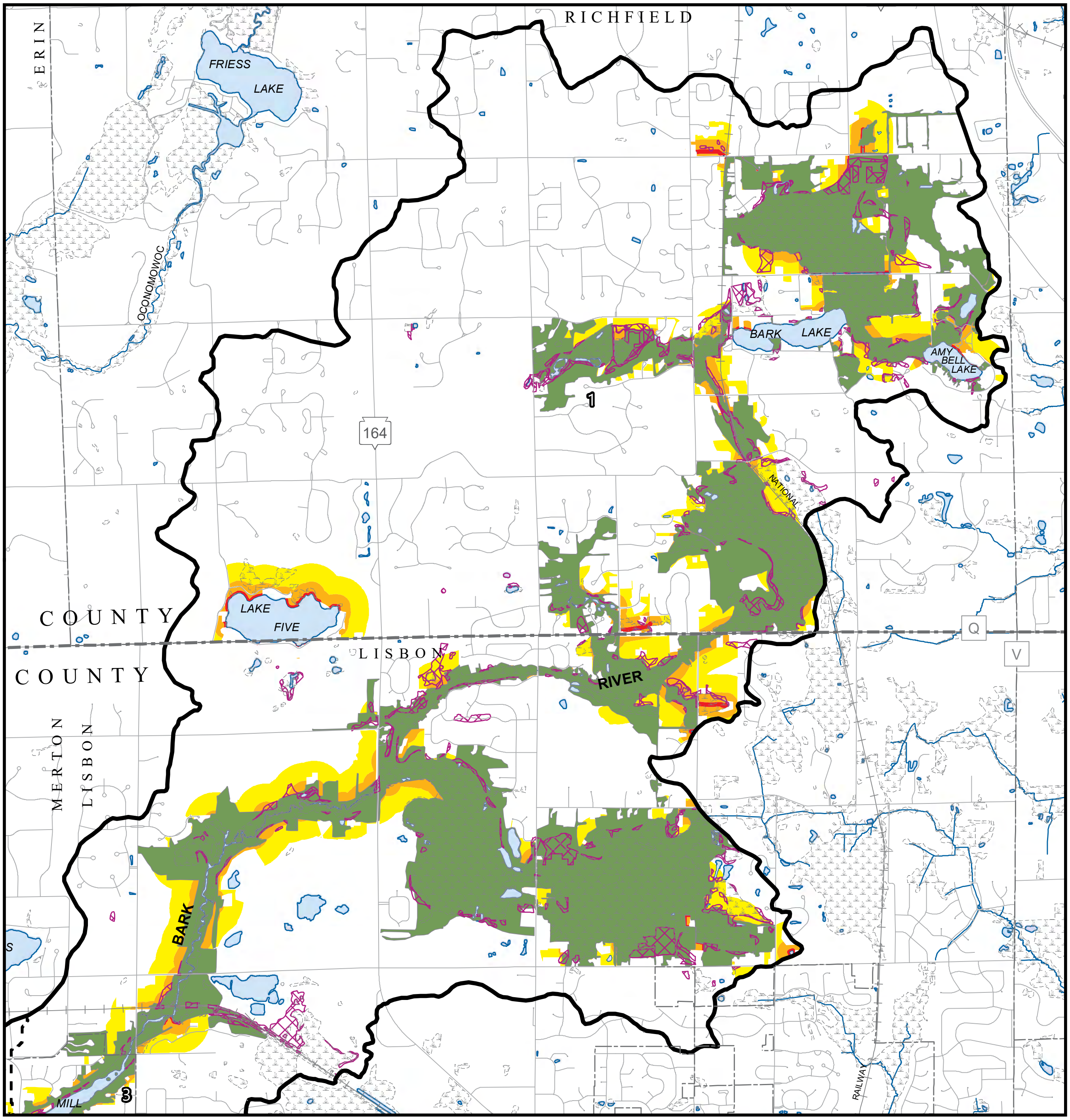
1 SUB-BASIN NUMBER

N

0 0.5 1 2 Miles

Source: SEWRPC

Map 2.32 (Inset 1)
Existing and Potential Riparian Buffers Within the Northern Portion of the Nagawicka Lake Watershed: 2015



EXISTING AND POTENTIAL RIPARIAN BUFFER

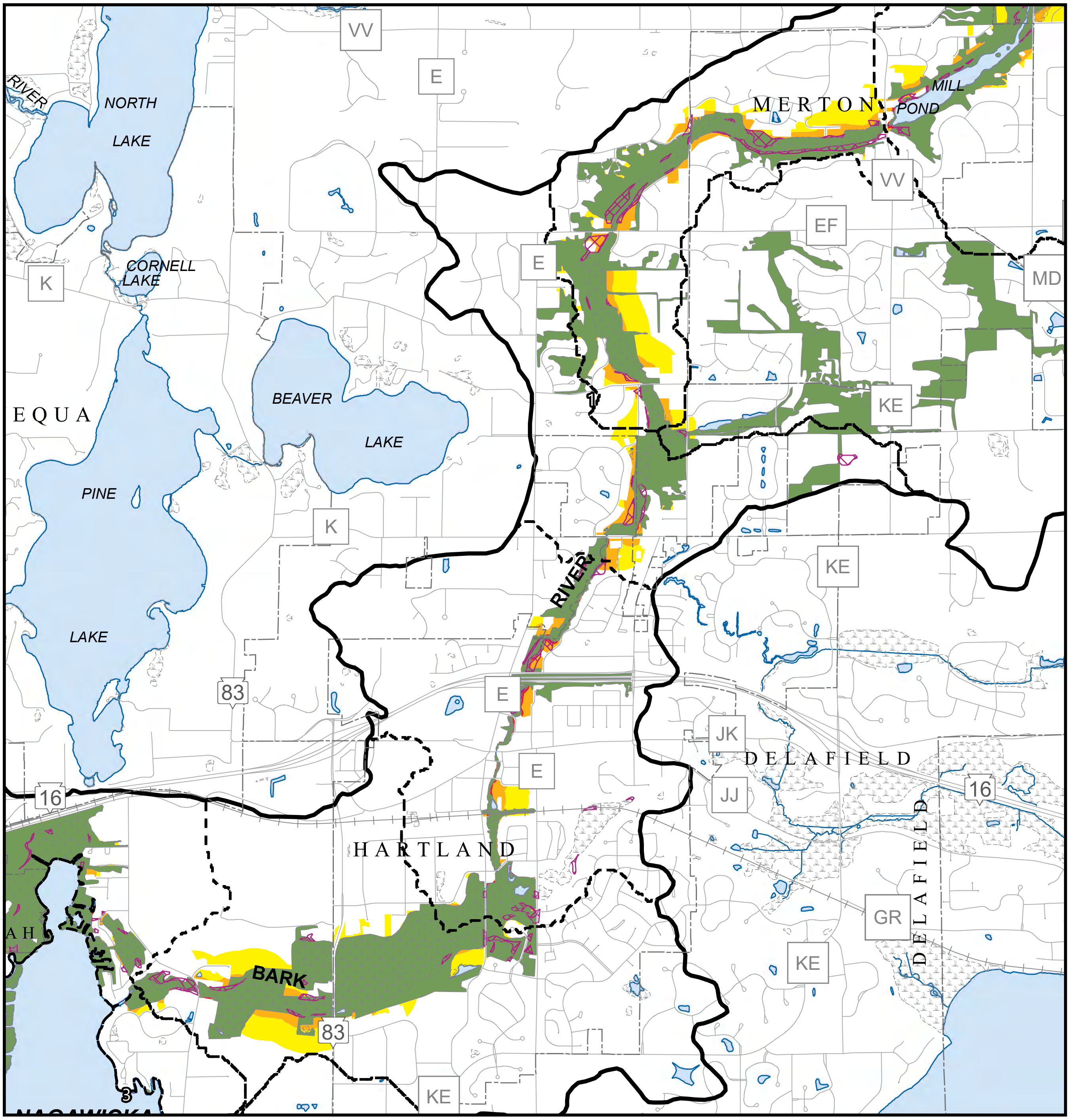
- EXISTING RIPARIAN BUFFER
- 75 FEET: MINIMUM RECOMMENDED BUFFER WIDTH
- 400 FEET: MINIMUM CORE HABITAT WIDTH FOR WILDLIFE PROTECTION
- 1000 FEET: OPTIMAL CORE HABITAT WIDTH FOR WILDLIFE PROTECTION
- SURFACE WATER
- STREAM
- WATERSHED BOUNDARY
- SUB-BASIN BOUNDARY
- POTENTIAL RESTORABLE WETLAND
- WETLAND
- 1 SUB-BASIN NUMBER

N

0 0.2 0.4 0.8 Miles

Source: SEWRPC

Map 2.32 (Inset 2)
Existing and Potential Riparian Buffers Within the Middle Portion of the Nagawicka Lake Watershed: 2015



EXISTING AND POTENTIAL RIPARIAN BUFFER

EXISTING RIPARIAN BUFFER

75 FEET: MINIMUM RECOMMENDED BUFFER WIDTH

400 FEET: MINIMUM CORE HABITAT WIDTH FOR WILDLIFE PROTECTION

1000 FEET: OPTIMAL CORE HABITAT WIDTH FOR WILDLIFE PROTECTION

SURFACE WATER

STREAM

WATERSHED BOUNDARY

SUB-BASIN BOUNDARY

POTENTIAL RESTORABLE WETLAND

WETLAND

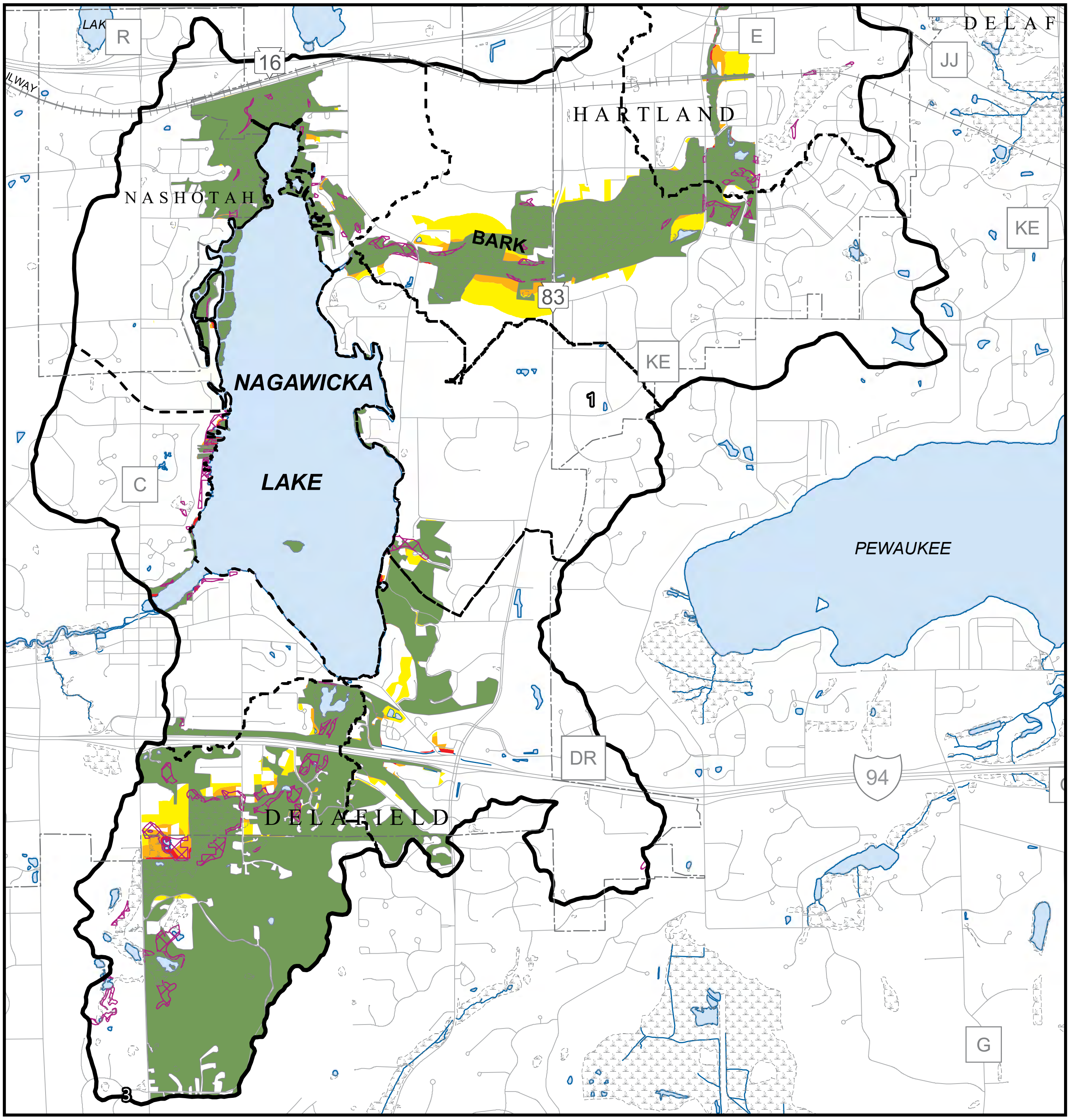
1 SUB-BASIN NUMBER

N

0 0.15 0.3 0.6 Miles

Source: SEWRPC

Map 2.32 (Inset 3)
Existing and Potential Riparian Buffers Within the Southern Portion of the Nagawicka Lake Watershed: 2015



EXISTING AND POTENTIAL RIPARIAN BUFFER

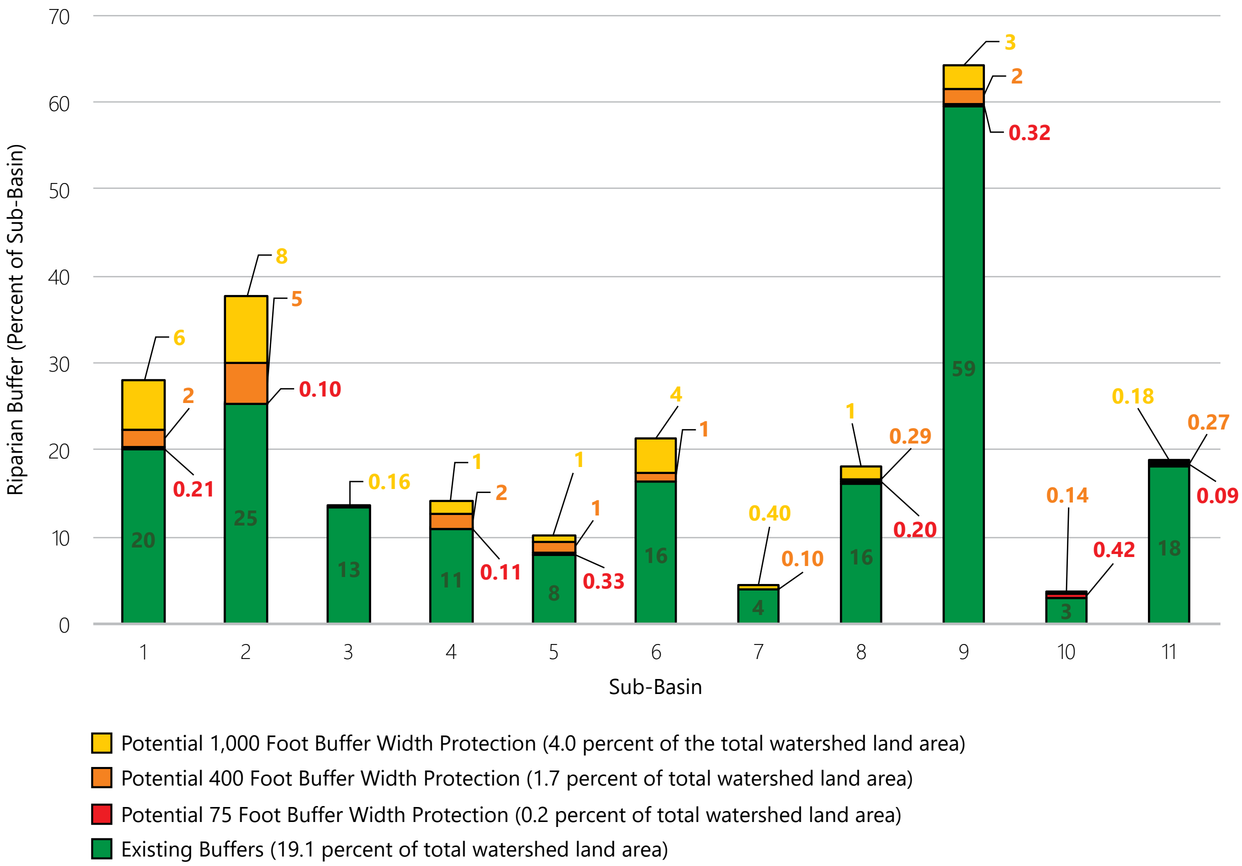
- EXISTING RIPARIAN BUFFER
- 75 FEET: MINIMUM RECOMMENDED BUFFER WIDTH
- 400 FEET: MINIMUM CORE HABITAT WIDTH FOR WILDLIFE PROTECTION
- 1000 FEET: OPTIMAL CORE HABITAT WIDTH FOR WILDLIFE PROTECTION
- SURFACE WATER
- STREAM
- WATERSHED BOUNDARY
- SUB-BASIN BOUNDARY
- POTENTIAL RESTORABLE WETLAND
- WETLAND
- 1 SUB-BASIN NUMBER

N

0 0.15 0.3 0.6 Miles

Source: SEWRPC

Figure 2.70
Percent Existing and Potential Buffers Within the Nagawicka Lake Watershed: 2015 (Areas Correspond to Map 2.32)



Source: SEWRPC

In addition, special consideration should be given to:

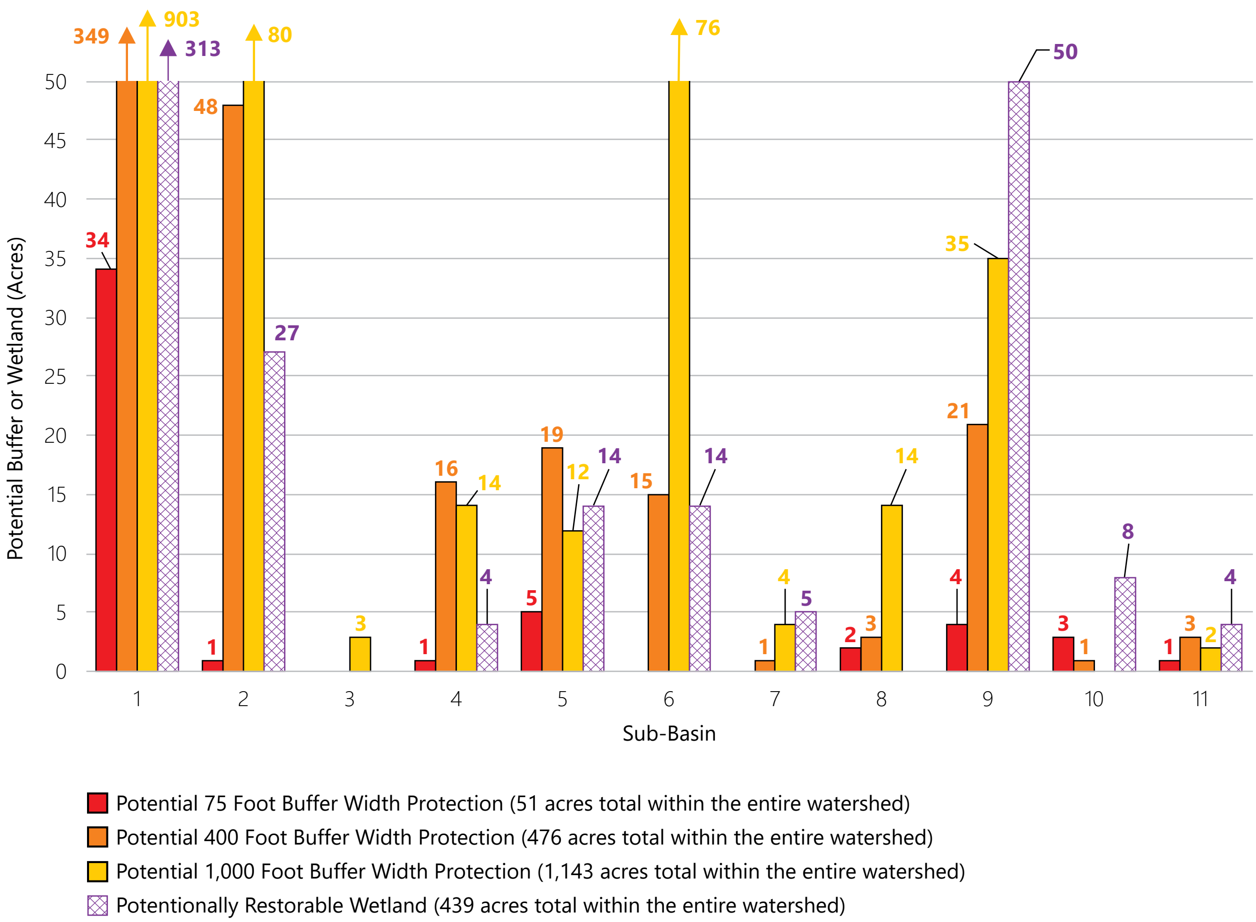
- Riparian buffers in locations designated as having high to very high groundwater recharge potential as shown on Map 2.13
- Connecting and expanding critical linkages among habitat complexes to protect wildlife abundance and diversity
- Connecting SEC lands and multiple INRAs throughout the Nagawicka Lake watershed to the larger PEC areas
- Building and expanding upon the existing protected lands as shown in Map 2.33

Collectively, this method represents an integrative, sound approach to enhance the corridor system and wildlife areas throughout the watershed.

Regulatory and Other Opportunities

Wisconsin Administrative Code Chapter NR 115, "Wisconsin's Shoreland Protection Program" establishes a minimum 35-foot development setback from the ordinary high-water mark of navigable lakes, streams, and rivers. A minimum tillage setback of five feet from the top of the channel of surface waters in agricultural lands is also specified under *Wisconsin Administrative Code* Chapter NR 151 "Runoff Management". Instream field observations in the watershed and orthophotography interpretation suggests that many areas along streams in the Nagawicka Lake watershed do not meet the five-foot tillage setback requirement. As

Figure 2.71
Potential Buffer or Restorable Wetland Acres Within the Nagawicka Lake Watershed: 2015 (Areas Correspond To Map 2.32)

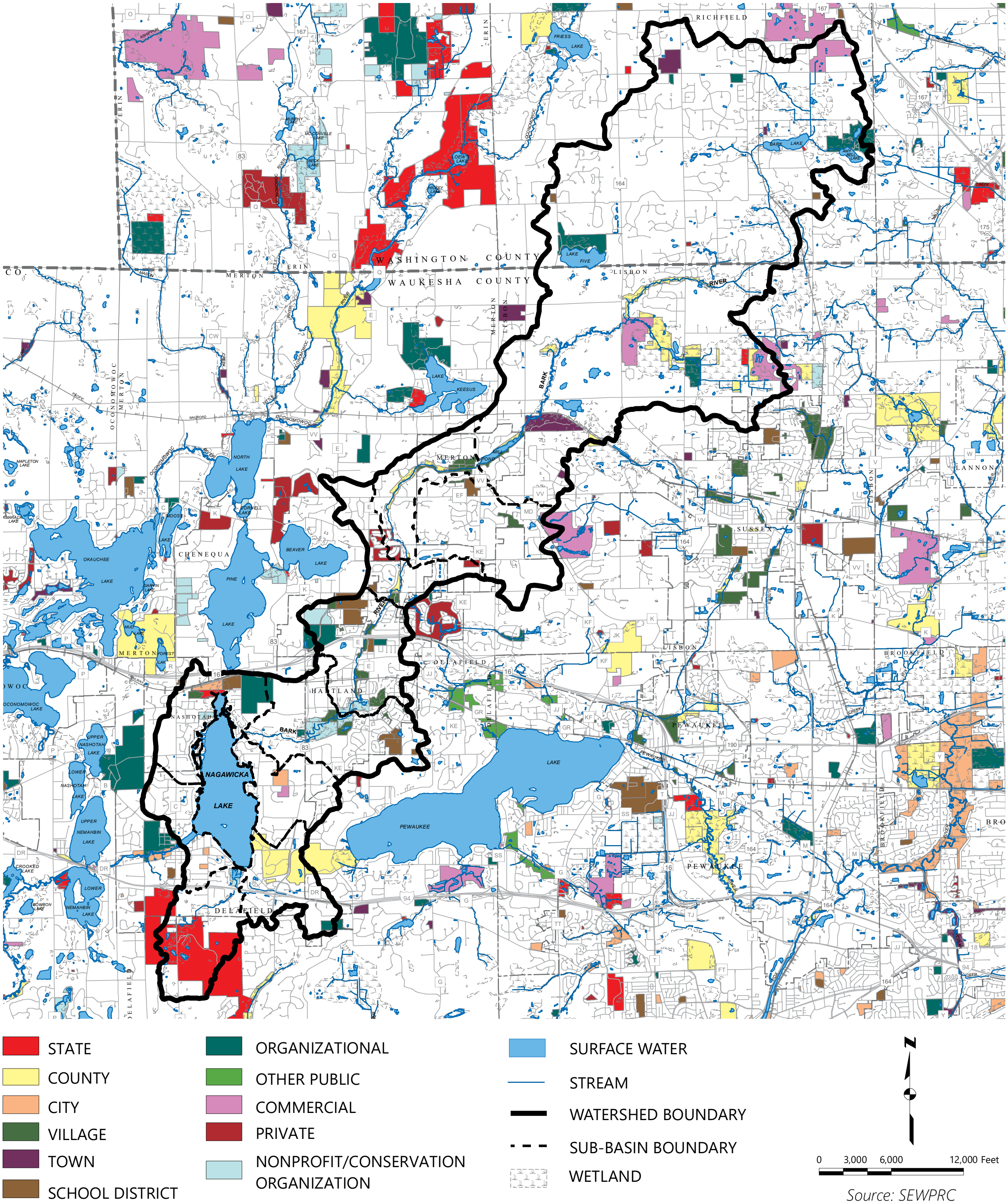


Source: SEWRPC

discussed in the preceding subsection, inadequate buffer between fields and a waterway can significantly increase sediment and phosphorus loading to waterbodies and can significantly limit wildlife. In addition, based upon the water quality and wildlife goals for this watershed, neither the 5-foot tillage setback nor the 35-foot buffer requirement are adequate to achieve the pollutant load reduction goals and resource protection concerns.

When considering setback distance, it is important to remember that crop yield losses are commonly greatest within flood prone areas. Therefore, adding buffer space to these areas commonly does limit production on prime agricultural land. Fields with high slopes (Map 2.3) and high soil erodibility (Map 2.5), fields where the minimum riparian buffer width of 75 feet is not being met (Map 2.32) and/or crop land is located within the 1-percent-annual probability-floodplain (Map 2.15), and fields containing potentially restorable wetlands within 1,000 feet of a waterway should be considered priority area for practices that provide riparian buffer function. In the 75-foot buffer areas, practices could include harvestable buffers, prohibition of certain high-intensity agricultural practices, and naturalization, many of which could be supported by subsidies to help land owners remain economically whole. Expanding riparian buffers to 400- and 1,000-foot widths, or greater to the extent practicable, is not likely practical until such time that agricultural land is converted to urban uses. At that time, it may be possible to require portions of the development accommodate such buffer widths as an integral part of the development design/review/approval process. Hence, that will likely be the best but perhaps last chance to establish such critical protective boundaries and/or open space and habitat connections around waterways.

Map 2.33
Protected Lands in the Nagawicka Lake Watershed: 2019



Source: SEWPRC

Primary environmental corridors (PEC) commonly enjoy a greater level of land use protection compared to secondary corridors, isolated natural resource areas, or designated natural areas outside of PECs. Therefore, the regulatory strategy to expand protections for vulnerable existing and potential riparian buffers would be to increase the extent of designated primary environmental corridor lands within the Nagawicka Lake watershed. In particular, two main PEC polygons in the Nagawicka Lake watershed are separated by a secondary environmental corridor along the Bark River within the Village of Hartland where development has significantly encroached on the River (see Map 2.20). The southern PEC polygon comprises Nagawicka Lake, the Bark River inlet, and extends south to include the Lapham Peak Woods. The northern PEC polygon includes the mainstem of the Bark River and its various tributaries including continuous connections to several headwater lakes (Lake Five, Bark Lake, and Amy Belle Lake) as shown on Map 2.20. Expanding connections to either of these PEC areas presents one of the best opportunities to expand primary environmental corridors in this watershed. Since these two areas already meet the minimum size requirements for designation as a PEC, any lands with sufficient natural resource features adjacent or connecting to this existing PEC could potentially be incorporated into this designation. For example, if connections could be made between the subject PEC and nearby SECs or INRAs, these might be upgraded to a PEC designation. This has the greatest potential where tributaries intersect with the mainstem of the Bark River, where expansion of riparian buffer lands could create connections and expand natural corridors.

Wetlands located within PEC lands have been designated as Advanced Delineation and Identification (ADID) wetlands under Section 404(b)(1) of the Federal Clean Water Act and are deemed generally unsuitable for the discharge of dredge and fill material. In addition, the nonagricultural performance standards set forth in Section NR 151.125 of the Wisconsin Statutes, require establishment of a 75-foot impervious surface protective area adjacent to these higher-quality wetlands. This designated protective area boundary is measured horizontally from the delineated wetland boundary to the closest impervious surface.[120] Hence, these wetlands would enjoy additional protection from filling and from being encroached upon by future development, enabling retention of their riparian buffer functions.

Best Management Practices and Programs for Riparian Buffers

A large portion of the existing and potential riparian buffers in the Nagawicka Lake watershed are privately owned urban and agricultural land use areas. Private landowners may choose to establish buffers. Although riparian buffers can mitigate negative water quality and habitat effects attributed to urban and agricultural land use, they cannot address all pollution and habitat concerns associated with human land use. Riparian buffers need to be combined with other management practices that help limit sediment and nutrient delivery to the riparian area. In urbanized areas, infiltration facilities, wet detention basins, porous pavements, green roofs, and rain gardens are examples of way to mitigate the effects of urban stormwater runoff. In agricultural areas, practices such as soil health initiatives, barnyard runoff controls, manure storage, filter strips, nutrient management planning, grassed waterways, and reduced tillage help improve runoff leaving agricultural lands. Therefore, best management practices to improve and protect water quality in both agricultural and urban areas are essential elements for the protection of water quality and quantity and wildlife within the Nagawicka Lake watershed (see Chapter 3 for more details).

Recent research suggests converting up to eight percent of cropland at the field edge from production to wildlife buffer habitat leads to increased yields in the cropped areas of the fields, and this positive effect becomes more pronounced with time.[121] As a consequence, despite the initial loss of cropland for habitat creation, overall yields for an entire field can be maintained, and even increased. Although it took about four years for the beneficial effects on crop yield to manifest themselves in this research project, increased yields were largely attributed to an increased abundance and diversity of crop pollinators within the wildlife habitat areas. Establishing buffers on marginally productive cropland would have even greater benefits. Therefore, establishing buffers on marginal cropland edges or potentially restorable wetland area may actually increase crop yields on a dollars per acre basis, so this practice may be economically feasible over the long-term. More importantly, these results also demonstrate that lower yielding field edges within

[120] *Runoff from impervious surfaces located within the protective area must be adequately treated with stormwater best management practices.*

[121] *R.F. Pywell et al., "Wildlife-friendly Farming Increases Crop Yield: Evidence for Ecological Intensification."* Proceedings of the Royal Society B: Biological Sciences *282 (1816), 2015.*

the Nagawicka Lake watershed can be better used as non-crop habitats to provide services supporting enhanced crop production, benefits for farmland biodiversity, and protection of water and soil health.[122]

In Wisconsin, the USDA offers technical assistance and funding to support establishment of riparian buffers and wetlands on agricultural lands. A 15-year contract must commonly be entered into by the landowner or operator and the land is only eligible under certain conditions, but normally must be devoted to agricultural production or use. Because the program requires a lengthy contract, it is often difficult to get farmers and/or landowners to commit to installing and maintaining riparian buffer strips. To overcome this, a custom program that offers a shorter time commitment (potentially five years) with a yearly payment incentive greater than what the USDA program offers, has found favor in other counties in the State, and could potentially be developed for the Nagawicka Lake watershed.

2.4 AQUATIC PLANT MANAGEMENT

Aquatic plant management is a visible and well-known concern for Lake residents and users. This section first examines the general need for aquatic plant management by quantifying the current state of aquatic plants in Nagawicka Lake. The most recent aquatic plant survey is then compared to past aquatic plant surveys. Lastly, management techniques are discussed that are appropriate given the Lake's physical conditions and ecosystem.

It is important to note that all healthy lakes have plants. In fact, in a nutrient-rich lake such as Nagawicka Lake, it is normal to have luxuriant plant growth in shallow areas. Nutrient-rich lakes are common in Southeastern Wisconsin due to nutrient-rich soil. Native aquatic plants form a foundational part of a lake ecosystem. Aquatic plants form an integral part of the aquatic food web, converting sediments and inorganic nutrients present in the water into organic compounds that are directly available as food to other aquatic organisms. In this process, known as *photosynthesis*, plants utilize energy from sunlight and release the oxygen required by many other aquatic life forms into the water. Aquatic plants also serve a number of other valuable functions in a lake ecosystem, including:

- Improving water quality and suppressing algal growth by using excess nutrients
- Providing habitat for invertebrates and fish
- Stabilizing lake bottom sediments
- Supplying food and oxygen to the lake through photosynthesis

A lake's water clarity, configuration, depth, nutrient availability, wave action, and fish population assemblage affect the abundance, diversity, and distribution of aquatic plants. Given the importance of native aquatic plants to overall lake health, it is desirable to periodically re-examine the abundance, distribution, and diversity of aquatic plants. Such data is contrasted to historical conditions in the Lake itself and other similar lakes; both comparisons help quantify the overall health of the aquatic plant community. A judgement can subsequently be made regarding the need for active aquatic plant management, and the locations and methods that provide the most overall apparent benefit to the Lake's health and user needs can be identified.

Phytoplankton and Macrophytes

Aquatic plants include microscopic algae ("phytoplankton") and larger plants ("macrophytes"). Phytoplankton is the term for a group of microscopic organisms that includes bacteria, protists, and algae. These organisms are aquatic and can all actively photosynthesize. Maintaining a healthy community of phytoplankton is essential for lake health, as these species form the foundation of the lake's food web and create oxygen required by other organisms, such as zooplankton and fish. However, an overabundance of phytoplankton, generally caused by excessive nutrient loads, can impair lake health by decreasing water clarity and reducing hypolimnetic oxygen. Since phytoplankton and macrophytes compete for nutrients, an abundance of macrophytes means fewer nutrients (usually phosphorus) available to algae, in turn reducing the abundance of free-floating algae and increasing water clarity.

[122] *Ibid.*

Macrophytes are often described using the terms *submerged, floating-leaf, free-floating,* and *emergent,* depending on where the plant is found in the lake ecosystem. *Submerged* plants are found in the main lake basin and, although most are rooted in the bottom substrate, some species, such as coontail (*Ceratophyllum demersum*) can become free-floating. *Floating-leaf* plants, such as water lilies, generally have large, floating leaves and are usually found in shallow water areas a few feet in depth or less that contain loose bottom sediments. *Free-floating* plants, such as duckweed (*Lemna* spp.), have small leaves, are not rooted to the sediment, and are often wind-blown around the waterbody. *Emergent* plants, which have leaves that emerge above the water, are commonly found along the shoreline areas of a lake, such as bulrushes and cattails. All four types have significant roles to play in the overall working of a lake's ecosystem.

Aquatic plants live in community with one another. They develop complex interactions and mutual dependencies that are of great significance in how these dynamic communities function within a lake. Native aquatic plant species are specifically adapted to local aquatic environments and many kinds of wildlife depend on the presence of specific native plant species for survival. For example, the seeds and tubers of Sago pondweed (*Stuckenia pectinata*) are an important food source for migratory waterfowl. In Wisconsin, the presence of native pondweeds is generally considered to be indicative of a healthy lake with good habitat for fish and aquatic life. Pondweeds provide good habitat and serve as food and shelter for a variety of aquatic organisms and waterfowl.

Maintaining a rich and diverse community of native species is important for every ecosystem as this:

- Helps sustain and increase the robustness of the existing system
- Increases the ability of an ecosystem to adapt to environmental changes
- Provides a spectrum of options for future decisions regarding the management of that system

Many factors—including lake configuration, depth, water clarity, nutrient availability, bottom substrate, wave action, and type and size of fish populations—determine the distribution and abundance of aquatic macrophytes in lakes, with most waterbodies within Southeastern Wisconsin naturally supporting abundant and diverse aquatic plant communities.

Aquatic Plants in Nagawicka Lake

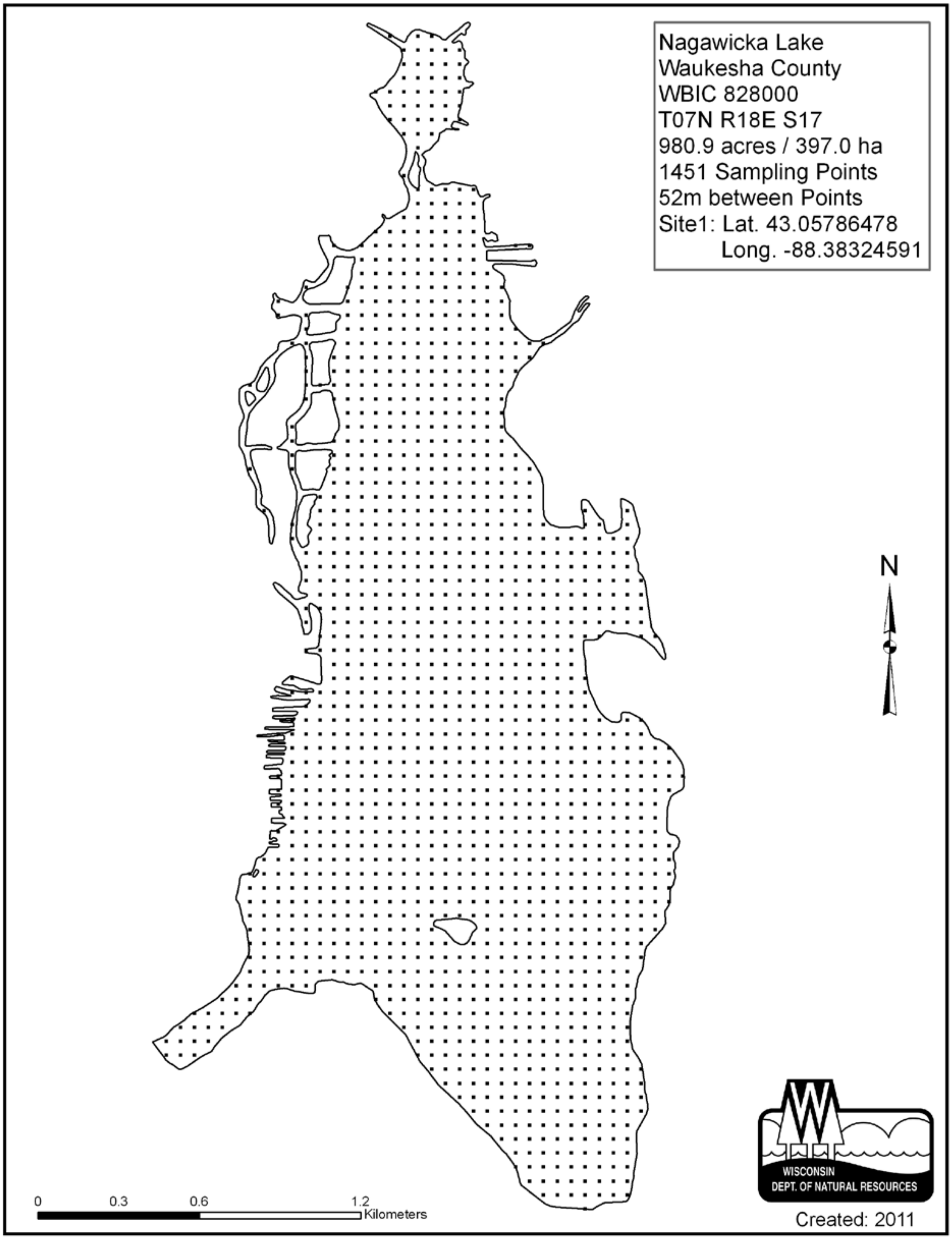
2016 Aquatic Plant Survey

To determine the current status of aquatic plants in Nagawicka Lake, Commission staff completed an aquatic plant survey during July and August 2016 using point-intercept methodology.[123] The point-intercept method uses predetermined sampling sites arranged in a grid pattern across the entire lake surface (see Figure 2.72); each site is located using global positioning system (GPS) technology. At each site, a single rake haul is taken and a qualitative assessment of the rake fullness, on a scale of zero to three, is then made for each species identified (see Figure 2.73). Of the 616 sites shallow enough to be sampled (water no greater than 15 feet deep), 543 had vegetation. The survey observed a total 32 plant species: 28 native and four nonnative species. See Table 2.20 for the complete list of aquatic plant species (submerged, floating, or emergent) that were found in the 2016 survey and for data regarding each plant's abundance and dominance. Appendix C contains maps showing the distribution of each species in Nagawicka Lake, along with key identification features and other pertinent information and the raw data from the survey in 2016. The five most abundant plant species, listed in descending order of abundance, were:

1. Muskgrasses (*Chara* spp.)
2. Eelgrass (*Vallisneria americana*)
3. Various-leaved milfoil *(Myriophyllum heterophyllum*)

[123] *Further details on the methodology can be found in Wisconsin Department of Natural Resources, Publication No. PUB-SS-1068, Recommended Baseline Monitoring of Aquatic Plants in Wisconsin: Sampling Design, Field and Laboratory Procedures, Data Entry and Analysis, and Applications, 2010.*

Figure 2.72
WDNR GPS Point Intercept Survey Sites for Nagawicka Lake



4. Coontail (*Ceratophyllum demersum*)

5. Spiny naiad (*Najas marina*)

Of these five species, only spiny naiad was nonnative. It should also be noted that of these five species, the top two (muskgrass and eelgrass) were significantly more abundant than all other submerged species, native or non-native, and that muskgrass was significantly more abundant than any other species in the Lake.[124] As shown in the distribution map for muskgrass, this highly dominant plant is found in greatest amounts along the western shoreline of the Lake, the southwest corner of the Lake between Horseshoe Bar and St. John's Bay, in the extreme north and south ends of the Lake, and in Zastrow Bay on the eastern side of the Lake.

Figure 2.73
WDNR Rake Fullness Assessments for Point-Intercept Aquatic Plant Sampling

Fullness Rating	Coverage	Description
1		Only few plants. There are not enough plants to entirely cover the length of the rake head in a single layer.
2		There are enough plants to cover the length of the rake head in a single layer, but not enough to fully cover the tines.
3		The rake is completely covered and tines are not visible.

Source: Wisconsin Department of Natural Resources

Some have identified muskgrass as growing at "nuisance" levels in Nagawicka Lake. Nevertheless, it is important to note that even though some people may perceive that a plant grows to nuisance levels, it may also be serving many beneficial functions. For example, muskgrass is largely responsible for marl formation which reduces phosphorus concentration (a key nutrient for plant and algae growth) in the Lake and helps improve water quality. Additionally, native species such as southern naiad, muskgrass, and elodea play major roles in providing shade, habitat, and food for fish and other important aquatic organisms. These plant species also play a significant role in reducing shoreline erosion since they can dampen waves that could otherwise damage shorelines. Furthermore, the shade that these plants provide helps reduce growth of undesirable plants such as Eurasian water milfoil and curly-leaf pondweed. These attributes underscore the importance of protecting native plant species and reinforce the concept that native plant removal or elimination should generally not be a significant component of sustainable, balanced aquatic plant management plans.

Biodiversity of Plants in Nagawicka Lake

With 24 different plant species (32 counting visuals)[125] of aquatic plants found as part of the 2016 aquatic plant survey, it is evident that Nagawicka Lake has a highly diverse aquatic plant community (see Figure 2.74). Two key aspects of a system's ecological integrity are: biological diversity *(*or, biodiversity*)*, and species richness. Although these two terms are often used somewhat interchangeably, the difference in their meaning is both subtle and significant. Diversity is based on the number of species present in a habitat along with the abundance of each of those species; it can be measured several ways, such as with the Simpson Diversity Index (see Table 2.21). Using this measure, a community dominated by one or two species would be considered less diverse than one in which several different species have similar abundances. For example, as shown in Table 2.20, Nagawicka Lake appears to be strongly dominated by muskgrass and eel grass compared to all other species. And yet, the Lake's Simpson Diversity Index value for Nagawicka Lake is 0.8 on a scale of zero to one, where zero equals no diversity and one equals infinite diversity. The reason that the Simpson value for a lake so strongly dominated by only two species so high lies in the second key aspect of this value—species richness*.* Species richness is simply the number of species in a habitat. As mentioned above, the 2016 aquatic plant survey of Nagawicka Lake identified 24 different plant species (32 counting visuals). Such a high number of different species offsets the fact that muskgrass and eel grass are so highly abundant relative to other species in the Lake. There is significant value in protecting the biodiversity of

[124] *Of the 543 sites sampled during 2016 that had aquatic vegetation, 391 locations had muskgrass and 284 sites had eelgrass.*

[125] *A "visual" observation refers to a species that, although not captured on the rake at a specific sampling site, was observed growing within several feet of the sampling site and whose presence was recorded but not quantified.*

Table 2.20
Nagawicka Lake Aquatic Plant Species Abundance: July/August 2016

Aquatic Plant Species	Native or Invasive	Number of Sites Found[a]	Frequency of Occurrence Within Vegetated Areas[b]	Average Rake Fullness[c]	Relative Frequency of Occurrence[d]	Visual Sightings[e]
Ceratophyllum demersum (coontail)	Native	47	8.66	1.40	4.20	1
Chara spp. (muskgrasses)	Native	385	70.90	1.94	34.50	6
Elodea canadensis (waterweed)	Native	36	6.63	1.25	3.20	1
Heteranthera dubia (water stargrass)	Native	10	1.84	1.40	0.90	0
Lemna minor (small duckweed)	Native	Present	0.00	0.00	0.00	20
Lemna trisulca (forked duckweed)	Native	3	0.55	1.00	0.30	0
Lythrum salicaria (purple loosestrife)	Invasive	Present	0.00	0.00	0.00	1
Myriophyllum heterophyllum (various-leaved milfoil)	Native	126	23.20	1.44	11.30	33
Myriophyllum spicatum (Eurasian water milfoil)	Invasive	11	2.03	1.27	1.00	8
Najas flexilis (bushy, or slender, pondweed)	Native	34	6.26	1.09	3.00	1
Najas marina (spiny, or brittle, naiad)[f]	Naturalized	44	8.10	1.18	3.90	3
Nuphar variegata (spatterdock)	Native	1	0.18	1.00	0.10	9
Nymphaea odorata (white water lily)	Native	2	0.37	1.00	0.20	53
Potamogeton crispus (curly-leaf pondweed)	Invasive	3	0.55	1.00	0.30	2
Potamogeton friesii (Fries' pondweed)	Native	7	1.29	1.29	0.60	0
Potamogeton gramineus (variable pondweed)[g]	Native	18	3.31	1.00	1.60	6
Potamogeton illinoensis (Illinois pondweed)[g]	Native	33	6.08	1.09	3.00	5
Potamogeton natans (floating-leaf pondweed)	Native	1	0.18	2.00	0.10	2
Potamogeton praelongus (white-stem pondweed)[g]	Native	2	0.37	1.00	0.20	0
Potamogeton richardsonii (clasping-leaf pondweed)[g]	Native	25	4.60	1.24	2.20	5
Potamogeton strictifolius (stiff pondweed)	Native	3	0.55	1.00	0.30	0
Potamogeton zosteriformis (flat-stem pondweed)	Native	14	2.58	1.07	1.30	2
Ranunculus sp. (white water crowfoot)	Native	2	0.37	1.00	0.20	0
Sagittaria sp. (Arrowhead)	Native	Present	0.00	0.00	0.00	1
Sparganium eurycarpum (Common bur-reed)	Native	Present	0.00	0.00	0.00	1
Spirodela polyrhiza (large duckweed)	Native	Present	0.00	0.00	0.00	20
Stuckenia pectinata (Sago pondweed)[g]	Native	37	6.81	1.24	3.30	8
Typha spp. (cattails)	Both[h]	Present	0.00	0.00	0.00	3
Utricularia vulgaris (common bladderwort)	Native	5	0.92	1.20	0.40	0
Vallisneria americana (eel-grass/wild celery)	Native	268	49.36	1.39	24.00	16
Wolffia columbiana (common watermeal)	Native	Present	0.00	0.00	0.00	20
Wolfia borealis (northern watermeal)	Native	Present	0.00	0.00	0.00	19

Note: Sampling occurred at 616 sampling sites on July 11th, 12th, and 13th and August 3rd, 8th, 9th, 10th, and 15th, 2016. 543 of these sites had vegetation. Red text indicates non-native and/or invasive species. See Appendix A for distribution maps and identifying features.

[a] *Number of Sites refers to the number of sites at which the species was retrieved and identified on the rake during sampling.*

[b] *Frequency of Occurrence, expressed as a percent, is the percentage of times a particular species occurred when there was aquatic vegetation present at the sampling site.*

[c] *Average rake fullness is the average amount, on a scale of 0 to 3, of a particular species at each site where that species was retrieved by the rake.*

[d] *Relative Frequency of Occurrence, expressed as a percent, is the frequency of that particular species compared to the frequencies of all species present.*

[e] *Visual Sightings is the number of sites where that particular species was visually observed within six feet of the actual rake haul location, but was not actually retrieved on the rake and was not, therefore, assigned a rake fullness measurement for that site. At sites where this occurred, the species was simply marked as "present" at that site. Recording the number of visual sightings helps give a better picture of species distribution throughout the lake.*

[f] *Spiny naiad was added to the NR 40 list as a restricted species in 2015, meaning it is not allowed to be transported, transferred, or introduced without a permit. Because the species is not native to Wisconsin and can become quite abundant, especially in lakes of poor water quality with hard water, it is currently considered a "naturalized" native species that can provide good habitat and food for fish and macroinvertebrates. Paul M. Skawinski, Aquatic Plants of the Upper Midwest 2nd Edition 2014; Through the Looking Glass: A Field Guide to Aquatic Plants 2nd Edition 2013.*

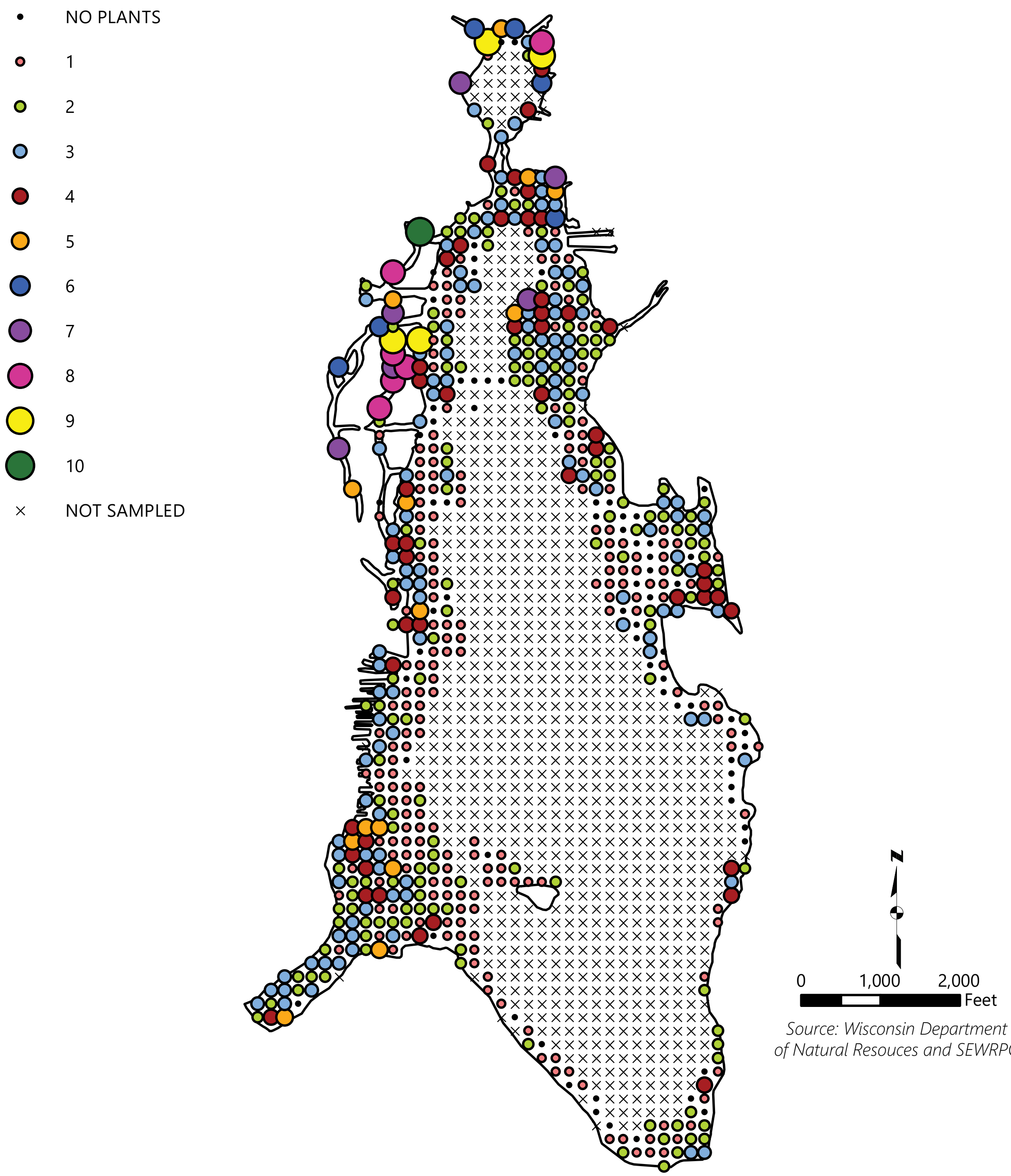
[g] *Considered a high-value aquatic plant species known to offer important values in specific aquatic ecosystems under Section NR 107.08 (4) of the* Wisconsin Administrative Code.

[h] *Cattails were observed and noted during the aquatic plant survey, but were not sampled. It is likely that there are both native and invasive Typha species present.*

Source: Wisconsin Department of Natural Resources

Figure 2.74
Aquatic Plant Survey Sites and Species Richness, Nagawicka Lake: July and August 2016

NUMBER OF NATIVE AQUATIC PLANT SPECIES



Source: Wisconsin Department of Natural Resouces and SEWRPC

Note: The above diagram presents the data for number of species observed in Nagawicka Lake at each sampling site during the 2016 aquatic plant survey. Sampling occurred between July 11, 2016, and August 15, 2016, at 616 sampling sites. Vegetation was found at 543 sites.

plants in Nagawicka Lake. Conserving biodiversity is critical to the long-term health of the Lake because it not only helps sustain and increase the robustness of the existing system, but also helps preserve a spectrum of options for future management.

Nonnative and Invasive Plants in Nagawicka Lake

In addition to native plants, the 2016 survey revealed the presence of *nonnative* and *invasive* aquatic plant species in Nagawicka Lake. The terms "nonnative" and "invasive" are often confused and are commonly incorrectly assumed to be synonymous. *Nonnative* is an overarching term describing living organisms introduced to new areas beyond their native range with intentional or unintentional human help. Nonnative species may not necessarily harm ecological function or human use values in their new environments. *Invasive species* are the subset of nonnative species that *do* have damaging impacts on the ecological health of their new environments and/or are considered a nuisance to human use values. In summary, all invasive species are nonnative, but not all nonnative species are invasive.

Introducing invasive species, either plants or animals, can severely disrupt both terrestrial and aquatic natural systems. Invasive species often reproduce prolifically since there are no natural predators to control their growth; this allows them to out-compete native species for space and other necessary resources with resultant devastating effects on other native species that depend on the availability of native plants and animals for survival.

Table 2.21
Nagawicka Lake Aquatic Plant Survey Statistics: July/August 2016

Total number of sites with vegetation	543
Total number of sites shallower than maximum depth of plants	616
Frequency of occurrence at sites shallower than maximum depth of plants	88.15
Simpson Diversity Index[a]	0.80
Maximum depth of plants (ft)	15.50
Average number of all species per site (shallower than max depth)	1.81
Average number of all species per site (veg. sites only)	2.06
Total number of sites visited	616
Average number of native species per site (shallower than max depth)	1.72
Average number of native species per site (veg. sites only)	1.97
Species Richness[b]	24
Species Richness (including visuals)	32

[a] *The Simpson Diversity Index is a measure of the degree of diversity in a habitat; it is based on the number of species present in a habitat along with the abundance of each of those species. Using this measure, a community dominated by one or two species would be considered less diverse than one in which several different species have a similar abundance. Simpson Diversity Index values range between 0 and 1, where 0 equals no diversity (a monoculture), and 1 = infinite diversity.*

[b] *Species richness is a simple value determined solely by the number of species in a habitat without regard for the relative abundances of each of those species.*

Source: SEWRPC

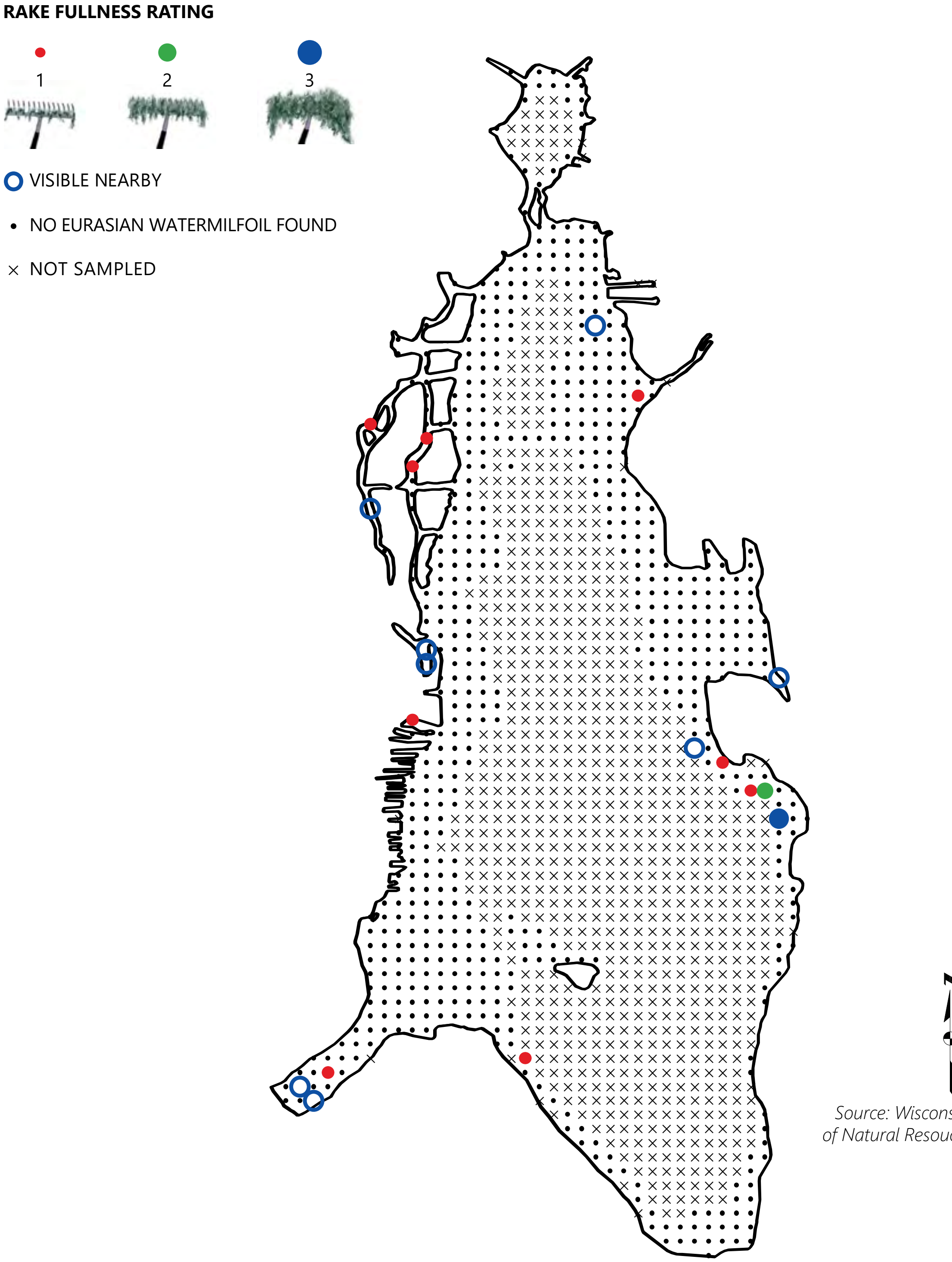
The 2016 aquatic plant survey identified several invasive and nonnative submergent species, including: invasive Eurasian water milfoil (*Myriophyllum spicatum*), the equally problematic invasive-native milfoil hybrids,[126] and nonnative curly-leaf pondweed (*Potamogeton crispus*). Fortunately, these plants are sparsely distributed throughout the Lake (see Figures 2.75 and 2.76).

Eurasian water milfoil has been known to cause severe recreational use problems in Southeastern Wisconsin lakes since it can grow to the water surface and can displace native plant species. Although populations are sparse, the presence of Eurasian water milfoil and its hybrid warrant conscientious monitoring and aquatic plant management in certain instances.

The curly-leaf pondweed growth cycle is different than most aquatic plants, with most growth occurring very early in the year. In the spring, curly-leaf pondweed can displace native aquatic plants and interfere with recreational use of a lake by forming dense mats at the water's surface. By mid-summer, curly-leaf pondweed starts to die off, causing plant fragments to accumulate on shorelines and resulting in a mid-summer flush of nutrients to lakes as the plants decompose. Since the 2016 plant survey was completed in July and August, curly-leaf pondweed may already have begun to senesce. Therefore, the 2016 sample results may not fully represent the true abundance of curly-leaf pondweed present earlier in the growing season. As a result, there may be a need to further evaluate and potentially actively control curly-leaf pondweed in the Lake.

[126] *In recent years, it has become evident that Eurasian water milfoil and native (or northern) water milfoil have begun to hybridize; the resultant hybrid strains – and they are many – cannot be reliably identified based on physical appearance alone, thus making identification and selection of the appropriate control method problematic.*

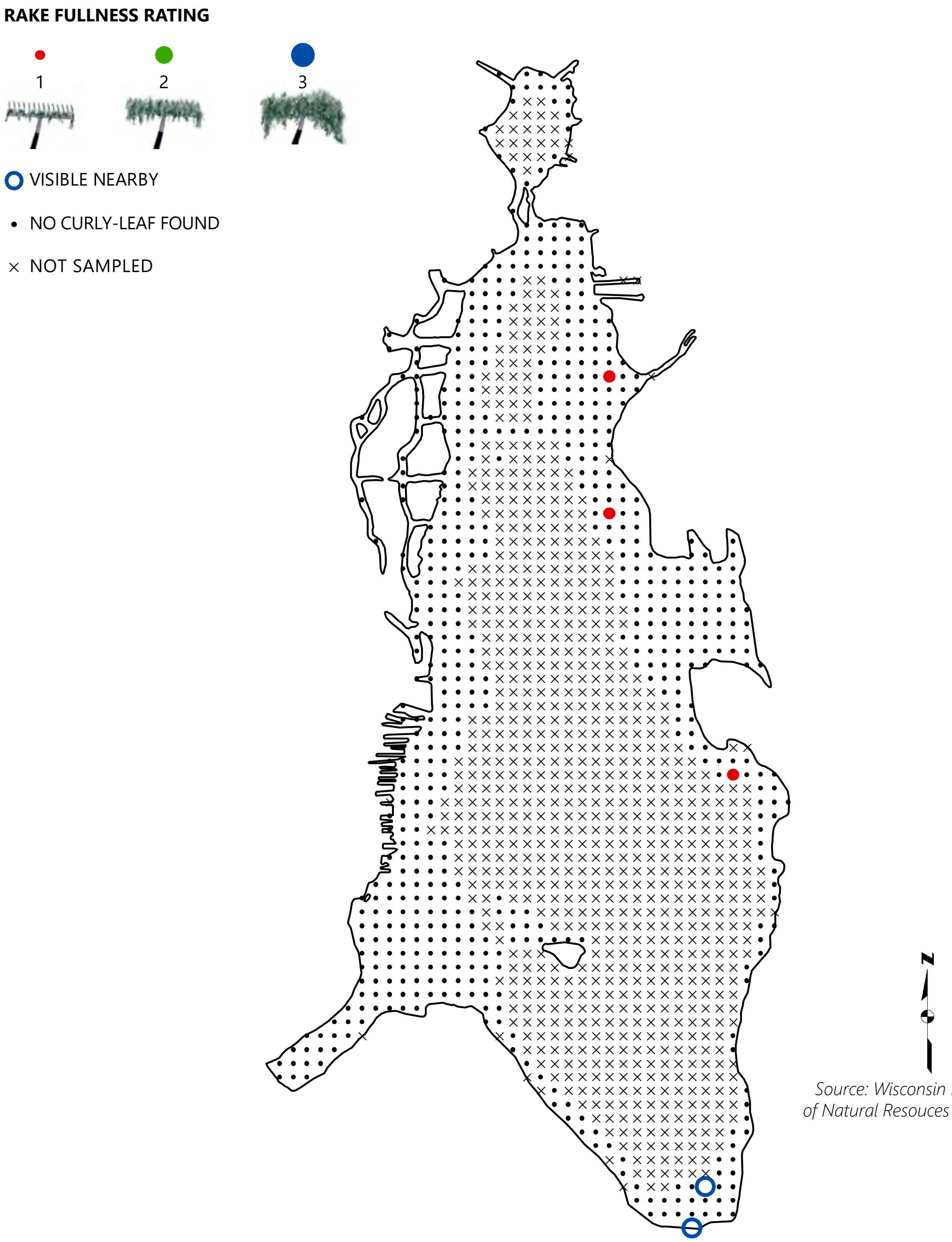
Figure 2.75
Eurasian Water Milfoil Occurrence in Nagawicka Lake: July and August 2016



Source: Wisconsin Department of Natural Resouces and SEWRPC

Note: Samples were collected between July 11 and August 15, 2016.

Figure 2.76
Curly-Leaf Pondweed Occurrence in Nagawicka Lake: July and August 2016



Source: Wisconsin Department of Natural Resouces and SEWRPC

Note: Samples were collected between July 11 and August 15, 2016.

Although starry stonewort (*Nitellopsis obtusa,* see Figure 2.77) was not found in Nagawicka Lake during the 2016 aquatic plant inventory, this new invasive aquatic plant species has been confirmed to occur in several lakes within Southeastern Wisconsin by Wisconsin DNR beginning in 2014. This is a major concern since starry stonewort has been spreading to other nearby lakes in Southeastern Wisconsin and no management methods have yet been found to successfully manage its growth. This species can form extremely dense vegetative mats that may affect aquatic plant community species richness and can impede recreational use. Dense growth of starry stonewort can also interfere with life-cycle critical functions of fish and other animals, including fish spawning.[127] The best control is to prevent its introduction to Nagawicka Lake (see more details in Chapter 3).

Past and Present Aquatic Plant Inventories

Abundant aquatic plants have been a management concern in Nagawicka Lake for decades. Although plants were treated chemically to control nuisance growth as early as the 1950s,[128] little is known regarding the methods or results of earlier aquatic plant control work.

Aquatic plant surveys have been conducted in Nagawicka Lake in 1993 by Aron and Associates, and 1997, 2004, 2011, and 2016 by the Commission. The 1993, 1997, and 2004 surveys used line-transect methodology,[129] while the 2011 and 2016 field surveys used the point-intercept method (described above). Although these two methodologies differ in their data collecting protocols, for purposes of aquatic plant management considerations the statistical differences resulting from the two methodologies is generally considered not sufficient to prevent reasonably reliable quantitative comparisons to be made for plant communities that have been assessed by both methods.[130] Thus, it is possible to make reasonably confident comparisons between the results of the 2004 survey which used the transect method, and the 2011 and 2016 surveys which used the point-intercept method; such comparison will be discussed in the following text.

As shown in Table 2.22, the number of different submerged species of aquatic plants in Nagawicka Lake was relatively stable in earlier surveys, with 12 species being identified in the 1993 and 11 species in 1997. During the 1997 survey, plant growth occurred in water depths of less than 15 feet in depth, with the exception of the southeastern and southwestern portions of the Lake where growth was sparse, perhaps due to the sudden change in depth. Just as is the case at present, muskgrass and wild celery (or eelgrass) were two of the most dominant plants in portions of the main Lake basin, while healthy populations of pondweeds were scattered throughout the Lake, generally in the five to 10-foot depth range. Eurasian water milfoil was also scattered throughout the Lake, but more commonly found between 10 feet and 15 feet of depth.

During the 2004 survey, 16 species of submerged aquatic plants were identified, including both native and nonnative species, and the Lake generally supported a healthy and diverse aquatic plant community. Both Eurasian water milfoil and curly-leaf pondweed were noted as present in the Lake and, although in significantly reduced numbers since the 1997 survey, Eurasian water milfoil was still noted to occur in extensive stands throughout the waterbody. At that time, it was assumed that the observed 2004 decline in Eurasian water milfoil and curly-leaf pondweed was likely nothing more than a normal periodicity, especially since Eurasian water milfoil populations had been observed to exhibit a similar type of periodicity

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[127] "Aquatic Invasive Species Quick Guide: Starry Stonewort (*Nitellopsis obtusa L.*)", *Golden Sands Resource Conservation and Development Council, Inc. This Quick Guide is part of a series on aquatic invasive species, and may be reproduced for educational purposes. Visit www.goldensandsrcd.org/aquatic-invasive-species to download this series of handouts. Developed by Golden Sands Resource Conservation & Development Council, Inc. as part of an aquatic invasive species education program, supported by a grant from the Wisconsin Department of Natural Resources. Maintained and updated by the Wisconsin Citizen Lake Monitoring Network.*

[128] *R.J. Poff and C. W. Threinen,* Surface Water Resources of Waukesha County, *Wisconsin Conservation Department, Madison, Wisconsin, 1963.*

[129] *The line-transect survey was developed from the grid sampling method of Jesson and Lound (1964). Twenty-five transects approximately 1,000 feet apart were established on a Lake map. Each transect (or line) extended from the shoreline to the maximum rooting depth within the Lake. Four sampling points were established on each transect line at 1.5 feet, 5.0 feet, 9.0 feet, and 11.0 feet. Each sampling point was a six-foot diameter circle. Each circle was divided into four quadrants and sampled with a garden rake.*

[130] *See SEWRPC Community Assistance Planning Report No. 193,* A Lake Protection Plan for Powers Lake, Kenosha and Walworth Counties, Wisconsin, *2011.*

elsewhere in southeastern Wisconsin lakes. However, as shown in Table 2.23, this marked decline in the amount of Eurasian water milfoil continued through 2011 and into 2016. What's more, this decline was not confined to Eurasian water milfoil numbers alone but has also occurred in curly-leaf pondweed numbers, while during this same time period (2004 – 2016), frequency of occurrence numbers for muskgrass and eel grass have been relatively stable (and dominant) in Nagawicka Lake. Of further interest is the increase in the number of submerged aquatic species in the Lake from 1993 to 2016 (see Table 2.22) as species richness has increased from 11 species in 1997, to 20 and 21 species in 2011 and 2016, respectively. Additionally, the 2016 survey observed, for the first time, the presence of white-stem pondweed (*Potamogeton praelongus*), a species known as an "indicator species" as it does not tolerate poor water quality conditions. Overall, the increase in native species in recent years, coupled with a decline in Eurasian water milfoil and curly leaf pondweed numbers along with the appearance of white-stem pondweed, are encouraging signs that there may be significant improvement occurring in the overall health of the Nagawicka Lake system; continued monitoring will bear out whether this is a long-term trend or not.

Figure 2.77
Starry Stonewort (*Nitellopsis obtusa*)

Source: Paul Skawinski

WDNR Designated Sensitive Areas

Sensitive Areas (also referred to as Critical Habitat Sites) are sites identified by the WDNR to have special importance biologically, historically, geologically, ecologically, or even archaeologically.[131] Sensitive Areas of aquatic vegetation commonly offer critical or unique fish and wildlife habitat, including life-cycle critical feeding, refuge, or life-stage requirements, or offer water quality or erosion control benefits. Currently, the WDNR designates five Sensitive Areas within Nagawicka Lake (see Map 2.34) because of the importance of these areas to the maintenance of good water quality conditions in, and the biological integrity of, the Lake. WDNR-designated Sensitive Areas must be accurately identified, embraced, and protected on-the-ground. Management work within Sensitive Areas commonly requires special practices and permits, conditions meant to help preserve ecological value and a healthy aquatic ecosystem (see Appendix D for more information on Nagawicka Lake's sensitive areas).

Aquatic Plant Management Alternatives

Aquatic plant management techniques can be classified into the following five groups.

- *Physical measures* – barriers, such as lake bottom coverings, are used to block sunlight and/or plant growth;
- *Biological measures* – natural agents, such as herbivorous insects, are used to impede undesirable plant growth;
- *Manual measures* – manipulation of plants by human beings. This can involve physical removal of plants by individuals using hand-held rakes or by hand-pulling individual plants.
- *Mechanical measures* – manipulation of plants using machines. This includes cutting (cut plants must be removed from the water), harvesting (where a machine both cuts and recovers cut plants and fragments) and suction harvesting; and,
- *Chemical measures* – introducing chemical compounds toxic to or restraining plant growth. This can include the use of aquatic herbicides to kill nuisance and nonnative aquatic plants.

[131] *Areas are identified as Sensitive Areas pursuant to Chapter NR 107 of the Wisconsin Administrative Code after a comprehensive examination and study completed by WDNR staff.*

Table 2.22
Submerged Aquatic Plant Species Found in Nagawicka Lake: 1993 – 2016

Aquatic Plant Species	Native or Invasive	1993	1997	2004	2011	2016
Ceratophyllum demersum (coontail)	Native	X	X	X	X	X
Chara spp. (muskgrasses)	Native	X	X	X	X	X
Elodea canadensis (waterweed)	Native	--	--	X	X	X
Heteranthera dubia (water stargrass)[a]	Native	--	--	X	X	X
Myriophyllum heterophyllum (various-leaved milfoil)[b]	Native	X	X	X	X	X
Myriophyllum spicatum (Eurasian water milfoil)	Invasive	X	X	X	X	X
Najas flexilis (slender naiad, bushy pondweed)	Native	X	X	X	X	X
Najas marina (spiny, or brittle, naiad)	Naturalized	X	X	X	X	X
Nitella spp. (stonewort)	Native	X	--	--	--	--
Potamogeton amplifolius (large-leaf pondweed)	Native	X	X	X	--	--
Potamogeton crispus (curly-leaf pondweed)	Invasive	X	X	X	X	X
Potamogeton foliosus (leafy pondweed)	Native	--	--	--	X	--
Potamogeton friesii (Fries' pondweed)	Native	--	--	--	--	X
Potamogeton gramineus (variable pondweed)	Native	--	--	--	X	X
Potamogeton illinoensis (Illinois pondweed)	Native	--	--	X	X	X
Potamogeton natans (floating-leaf pondweed)	Native	--	--	--	X	X
Potamogeton nodosus (long-leaf pondweed)	Native	--	--	--	X	--
Potamogeton praelongus (white-stem pondweed)	Native	--	--	--	--	X
Potamogeton pusillus (small pondweed)	Native	--	--	--	X	--
Potamogeton richardsonii (clasping-leaf pondweed)	Native	X	X	X	X	X
Potamogeton strictifolius (stiff pondweed)	Native	--	--	--	--	X
Potamogeton zosteriformis (flat-stem pondweed)	Native	X	X	X	X	X
Ranunculus sp. (white water crowfoot)	Native	--	--	--	--	X
Stuckenia pectinata (Sago pondweed)[c]	Native	--	--	X	X	X
Utricularia vulgaris (common bladderwort)	Native	--	--	X	X	X
Vallisneria americana (eel-grass/wild celery)	Native	X	X	X	X	X
Total number of species		12	11	16	20	21

Note: Red text indicates non-native or invasive species.

[a] *In recent years, water stargrass has received a revised scientific name:* Heteranthera dubia*; its prior name was* Zosterella dubia.

[b] *In 2004 and 2011, this was identified as northern water milfoil (*Myriophyllum sibiricum*), but is likely to have been misidentified.*

[c] *In recent years, Sago pondweed has received a revised scientific name:* Stuckenia pectinata*; its prior name was* Potamogeton pectinatus.

Source: SEWRPC

More information regarding these alternatives is provided in the following subsections. All control measures are stringently regulated and most require a State of Wisconsin permit. Chemical controls, for example, require a permit and are regulated under Chapter NR 107, "Aquatic Plant Management," of the *Wisconsin Administrative Code*, while placing bottom covers (a physical measure) requires a WDNR permit under Chapter 30 of the *Wisconsin Statutes*. All other aquatic plant management practices are regulated under Chapter NR 109, "Aquatic Plants: Introduction, Manual Removal and Mechanical Control Regulations," of the *Wisconsin Administrative Code*.

The aquatic plant management elements described in the following text consider alternative management measures consistent with the provisions of Chapters NR 103, "Water Quality Standards for Wetlands," NR 107, and NR 109 of the *Wisconsin Administrative Code*. Furthermore, the alternative aquatic plant management measures are consistent with the requirements of Chapter NR 7, "Recreational Boating Facilities Program," and with the public recreational boating access requirements relating to eligibility under the State cost-share grant programs set forth in Chapter NR 1, "Natural Resources Board Policies," of the *Wisconsin Administrative Code*.

Physical Measures

Lake bottom covers and light screens control rooted plants by creating a physical barrier that reduces or eliminates plant-available sunlight. They are often used to create swimming beaches on muddy shores,

Table 2.23
Importance/Dominance of Submerged Aquatic Plant Species, Nagawicka Lake: 2004 – 2016

Aquatic Plant Species	June 2004 Importance Value	2011 Dominance Value[a]	2016 Dominance Value[a]
Chara spp. (muskgrasses)	137	47.9	137.38
Vallisneria americana (eel-grass/wild celery)	132	46.2	68.69
Myriophyllum heterophyllum (various-leaved milfoil)	106[b]	27.7[b]	33.52
Ceratophyllum demersum (coontail)	72	39.6	12.15
Najas marina (spiny, or brittle, naiad)	1	11.9	9.58
Stuckenia pectinata (Sago pondweed)[c]	10	6.3	8.47
Elodea canadensis (waterweed)	16	5.6	8.29
Najas flexilis (bushy pondweed or slender naiad)	4	15.3	6.81
Potamogeton illinoensis (Illinois pondweed)	20	9.1	6.63
Potamogeton richardsonii (clasping-leaf pondweed)	17	6.3	5.71
Potamogeton gramineus (variable pondweed)	--	5.8	3.31
Potamogeton zosteriformis (flat-stem pondweed)	71	2.0	2.76
Myriophyllum spicatum (Eurasian water milfoil)	59	3.6	2.58
Heteranthera dubia (water stargrass)[d]	2	7.7	2.58
Potamogeton friesii (Fries' pondweed)	--	1.1[e]	1.66
Utricularia vulgaris (common bladderwort)	1	3.9	1.10
Potamogeton crispus (curly-leaf pondweed)	22	0.9	0.55
Potamogeton strictifolius (stiff pondweed)	--	--	0.55
Potamogeton natans (floating-leaf pondweed)	--	0.3	0.37
Potamogeton praelongus (white-stem pondweed)	--	--	0.37
Ranunculus sp. (white water crowfoot)	--	--	0.37
Sagittaria sp. (Arrowhead)	--	--	0.00
Potamogeton amplifolius (large-leaf pondweed)	6	--	--
Nitella sp. (stonewort)	--	--	--
Potamogeton foliosus (leafy pondweed)	--	2.0	--
Potamogeton nodosus (long-leaf pondweed)	--	0.8	--
Total Number of Species	16	20	22

Note: Sampling occurred at 616 sampling sites; 543 sites had vegetation. Invasive and non-native species are identified with red text.

[a] *The* dominance value *of a species is derived from a combination of how often it was observed at sampling sites that had some kind of vegetation present and its relative density at those sites; it provides an indication of the dominance of a species within a community; statistically equivalent to* importance value.

[b] *This was identified as northern water milfoil (*Myriophyllum sibiricum*), but is likely to have been misidentified.*

[c] *In recent years, Sago pondweed has received a revised scientific name:* Stuckenia pectinata*; its prior name was* Potamogeton pectinatus.

[d] *In recent years, water stargrass has received a revised scientific name:* Heteranthera dubia*; its prior name was* Zosterella dubia.

[e] *This was identified as small pondweed (*Potamogeton pusillus*), but is likely to have been misidentified.*

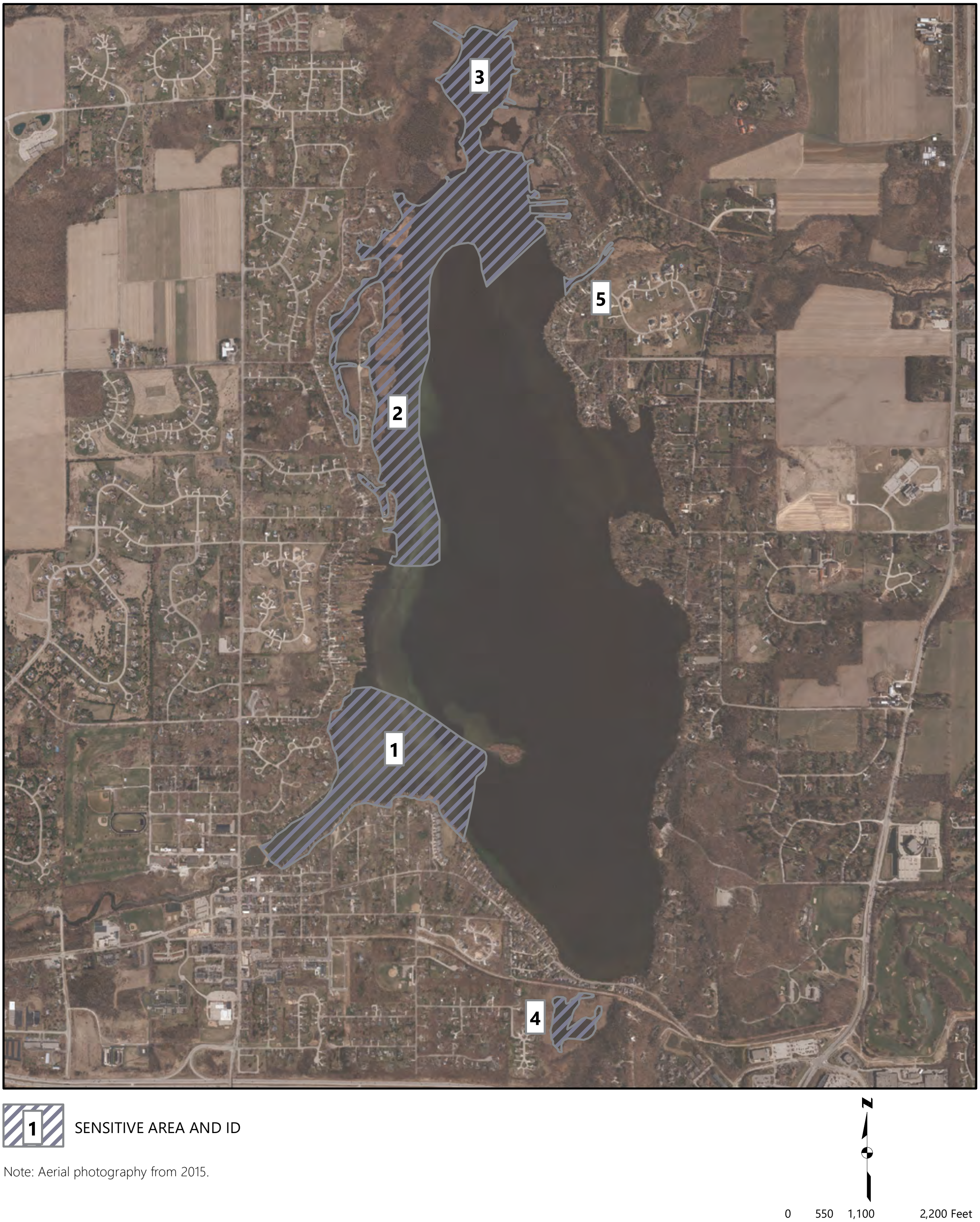
Source: SEWRPC

to improve the appearance of lakefront property, and to open channels for motorboats. Various materials can be used with varied levels of success. For example, pea gravel, which is usually widely available and relatively inexpensive, is often used as a bottom cover material despite the fact that plants readily recolonize pea gravel deposited upon lake bottoms. Other options include synthetic materials such as polyethylene, polypropylene, fiberglass, and nylon. Synthetic barriers can provide relief from rooted plants for several years. However, they are susceptible to disturbance by watercraft propellers and to gas build-up from decaying plant biomass trapped under the barrier and therefore may have to be placed and removed each year. Whatever the case, the WDNR does not permit these kinds of controls. Consequently, lake-bottom covers are not a viable aquatic plant control strategy for the Lake.

Biological Measures

Biological controls offer an alternative approach to controlling nuisance or exotic plants. Biological control techniques traditionally use herbivorous insects that feed upon nuisance plants. This approach has been

Map 2.34
Sensitive Areas Within Nagawicka Lake: 2019



Note: Aerial photography from 2015.

Source: WDNR and SEWRPC

effective in some southeastern Wisconsin lakes.[132] An example of this type of control is the milfoil weevil (*Eurhychiopsis lecontei).* Milfoil weevils do best in lakes with dense Eurasian water milfoil beds where the plants reach the surface and are close to shore. Furthermore, to prosper, milfoil weevils prefer lakes with natural shoreline areas where leaf litter provides habitat for over-wintering, have little boat traffic, and which have balanced panfish populations.[133] This technique is not presently commercially available, making the use of introduced milfoil weevils a non-viable option. Additionally, since the Lake only has a small population of Eurasian water milfoil, has highly developed shore areas, and has intense boat activity, milfoil weevils are not well suited for application on most of Nagawicka Lake. However, such an application may be an option in the future in the northeastern portion of the Lake from the Bark River north to the kettle, which has more natural shorelines.

Manual Measures

Manual removal of specific types of vegetation provides a highly selective means of controlling nuisance aquatic plant growth, including invasive species such as Eurasian water milfoil.

Two common manual removal methods are: raking and hand-pulling. Each rely on physically removing target plants from the Lake. Removing plant material from the Lake reduces nutrient loads and the volume of materials that contribute to lake-bottom sediment accumulation, helping to incrementally maintain water depths and improve water quality. Furthermore, removing target plants reduces their reproductive potential. Raking and hand-pulling are described in more detail in the following paragraphs.

Raking is conducted in nearshore areas with specially designed hand tools. Raking allows nonnative plants to be removed in shallow nearshore areas and also provides a safe and convenient method to control aquatic plants in deeper nearshore waters around piers and docks. The advantages associated with using rakes include: 1) the tools are relatively inexpensive ($100 to $150 each), 2) they are easy to use, 3) they generate immediate results, and 4) they immediately remove plant material from a lake (including seeds and plant fragment) thereby reducing nutrient release and sedimentation from decomposing plant material and reducing the reproductive potential of target plants. Should Nagawicka Lake residents decide to implement this method of control, an interested party could acquire a number of these specially designed rakes for riparian owners to use on a trial basis.).

If lake users are satisfied with rakes, additional property owners should be encouraged to purchase and use rakes. In areas where other management efforts are not feasible, raking is a viable option to manage overly abundant or undesirable plant growth.

The second manual control method—hand-pulling whole plants (stems, roots, leaves, and seeds) where they occur in isolated stands—provides an alternative means of controlling plants such as Eurasian water milfoil and curly-leaf pondweed. This method is particularly helpful when attempting to target nonnative plants in the high growth season when native and nonnative species often coexist and intermix. This method is more highly selective than rakes, mechanical removal, and chemical treatments, and if carefully applied, is less damaging to native plants. Additionally, physically removing plant materials prevents sedimentation and nutrient release from targeted plants, which incrementally helps maintain water depth and better water quality. Physical removal also reduces the amount of target plant seed and plant fragments, which helps reduce the reproductive ability of the target plants. Given these advantages, hand-pulling Eurasian water milfoil and curly-leaf pondweed is considered a viable option in Nagawicka Lake, where practical. Volunteers or homeowners could employ this method, as long as they are properly trained to identify Eurasian water milfoil, curly-leaf pondweed, or any other invasive plant species of interest. WDNR provides a wealth of guidance materials, including an instructional video describing manual plant removal, to help educate volunteers and homeowners.

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[132] *B. Moorman,* A Battle with Purple Loosestrife: A Beginner's Experience with Biological Control*, Lake Line, Vol. 17, No. 3, pp. 20-21, 34-37, September 1997; see also, C.B. Huffacker, D.L. Dahlsen, D.H. Janzen, and G.G. Kennedy,* Insect Influences in the Regulation of Plant Population and Communities, *pp. 659-696, 1984; and C.B. Huffacker and R.L. Rabb, editors,* Ecological Entomology*, John Wiley, New York, New York, USA.*

[133] *Panfish such as bluegill and pumpkinseed are predators of herbivorous insects. High populations of panfish lead to excess predation of milfoil weevils.*

Pursuant to Chapter NR 109 of the *Wisconsin Administrative Code*, aquatic plants may be raked or hand-pulled without a WDNR permit under the following conditions:

- Eurasian water milfoil, curly-leaf pondweed, and purple loosestrife may be removed if the native plant community is not harmed in the process.

- No more than 30 lineal feet of shoreline may be cleared, and this total must include shoreline lengths occupied by docks, piers, boatlifts, rafts, and areas undergoing other plant control treatment. In general, regulators allow vegetation to be removed up to 100 feet out from the shoreline.

- Plant material that drifts onto the shoreline must be removed.

- The shoreline is not a designated sensitive area.

- Raked and hand-pulled plant material must be removed from the lake.

Any other manual removal program requires a State permit, unless specifically used to control designated nonnative invasive species such as Eurasian water milfoil. In general, State manual aquatic plant removal permits call for all hand-pulled material to be removed from the lake. No mechanical equipment (e.g., towing equipment such as a rake behind a motorized boat or using weed rollers) may be legally used without a WDNR-issued permit. Recommendations regarding hand-pulling and raking are included in Chapter 3.

Mechanical Measures

Two methods of mechanical harvesting are currently permitted and employed in Wisconsin. These methods include use of an aquatic plant harvester (mechanical harvesting) and suction harvesting. More details about each are presented in the following text.

<u>Plant Harvesting</u>

Aquatic plants can be mechanically gathered using specialized equipment known as harvesters. This equipment consists of an adjustable cutting apparatus that cut plants at selected depths from the surface to up to about five feet below the water surface and a collection system (e.g., a conveyor and a basket) that gathers most cut plant material. Mechanical harvesting can be a practical and efficient means of controlling sedimentation and plant growth, as it removes plant biomass which would otherwise decompose and release nutrients and sediment into a lake. Mechanical harvesting is particularly effective for large-scale projects.

An advantage of mechanical harvesting is that the harvester, when properly operated, “mows” the tops of aquatic plants, thus typically leaving enough living plant material in the lake to provide shelter for aquatic wildlife and to stabilize lake-bottom sediment. None of the other aquatic plant management methods leave living plant material in place after treatment**.** Aquatic plant harvesting also has been shown to facilitate growth of suppressed native aquatic plants by allowing light to penetrate to the lakebed. This is particularly effective when controlling invasive plant species that commonly grow very early in the season when native plants have not yet emerged or appreciably grown. Finally, harvesting does not kill native plants in the way that other control methods do. Instead, this method simply trims them back.

A disadvantage of mechanical harvesting is that the harvesting process may fragment plants and, thereby, unintentionally facilitate the spread of Eurasian water milfoil and starry stonewort, both of which utilize fragmentation as a means of propagation, particularly in areas where plant roots have been removed. This further emphasizes the need to prevent harvesting that removes the roots of native plants. Harvesting may also agitate bottom sediments in shallow areas, thereby increasing turbidity and resulting in deleterious effects such as smothering of fish breeding habitat and nesting sites. Agitating bottom sediment also increases the risk of nonnative species recolonization, as invasive species tend to thrive on disrupted and/or bare lake bottom. To this end, most WDNR-issued permits do not allow deep-cut harvesting in water less than three feet deep,[134] which limits the utility of this alternative in many littoral areas. Nevertheless, if employed

[134] *Deep-cut harvesting is harvesting to a distance of only one foot from the lake bottom. This is not allowed in shallow areas because it is challenging to properly ensure that the harvester does not hit the lake bottom in these areas.*

correctly and carefully under suitable conditions, harvesting can benefit navigation lane maintenance and can ultimately reduce regrowth of nuisance plants while maintaining native plant communities.

Some cut plant fragments can escape the harvester's collection system. This negative side effect is fairly common. To compensate for this, most harvesting programs include a plant pickup program like the one Nagawicka Lake currently employs. The plant pickup program uses the harvester to gather and collect significant accumulations of floating plant debris and includes regular pickup from the docks of lakefront property owners who actively rake plant debris onto their docks.[135] This kind of program, when applied systematically, can reduce plant propagation from plant fragments and can help alleviate the negative aesthetic consequences of plant debris accumulating on shorelines. However, it is important to note that plant fragments from normal boating activity on Nagawicka Lake (particularly during weekends) create far more plant fragments than generated from the harvesting operations, with significant accumulations occurring in the northeastern shoreline due to prevailing wind conditions.[136] Therefore, this plant pickup program is essential for the protection of this Lake, even in areas where harvesting has not recently occurred.

<u>Suction Harvesting (DASH)</u>

An alternative aquatic plant harvesting method has emerged called Diver Assisted Suction Harvesting (DASH). First permitted in 2014, DASH (also known as suction harvesting) is a mechanical process where divers identify and pull select aquatic plants by their roots from the lakebed and then insert the entire plant into a suction hose that transports the plant to the lake surface for collection and disposal. The process is essentially a more efficient and wide-ranging method for hand-pulling aquatic plants. Such labor-intensive work by skilled professional divers is, at present, a costly undertaking and long-term evaluations will be needed to evaluate the efficacy of the technique. Nevertheless, many apparent advantages are associated with this method, including: 1) lower potential to release plant fragments when compared to mechanical harvesting, raking, and hand-pulling, thereby reducing spread and regrowth of invasive plants like Eurasian water milfoil; 2) increased selectivity in terms of plant removal when compared to mechanical and hand harvesting, thereby reducing the loss of native plants; and 3) lower potential for disturbing fish habitat. However, given how costly DASH can be with the minimal amount of Eurasian water milfoil in the Lake, DASH is not considered a viable control option for managing Eurasian water milfoil throughout Nagawicka Lake. However, DASH can provide relief of nuisance native and nonnative plants around piers. If individual property owners choose to employ DASH, an NR 109 permit is required.

Both mechanical harvesting and suction harvesting are regulated by WDNR and require a permit. Non-compliance with permit requirements is legally enforceable and may lead to fines and/or complete permit revocation. The information and recommendations provided in this report will help frame permit requirements. Permits can be granted to cover up to a five-year period.[137] At the end of that period, a new plant management plan must be developed. The updated plan must consider the results of a new aquatic plant survey and must evaluate the success or failure and effects of completed plant management activities.[138] These plans and plan execution are overseen by the WDNR aquatic invasive species coordinator for the region.[139]

Chemical Measures

Use of chemical herbicides in aquatic environments is stringently regulated and requires a WDNR permit and WDNR staff oversight during application. Chemical herbicide treatment is a short-term method to control heavy growths of nuisance aquatic plants. Chemicals are applied to growing plants in either liquid or granular form. The advantages of using chemical herbicides to control aquatic plant growth include

[135] *The plant pick-up program could also collect plant materials generated by landowner raking and/or hand-pulling along their own shoreline.*

[136] *Personal Communication, Tom Hafner, City of Delafield Department of Public Works.*

[137] *Five-year permits are granted so that a consistent aquatic plant management plan can be implemented over that time. This process allows the aquatic plant management measures that are undertaken to be evaluated at the end of the permit cycle.*

[138] *Aquatic plant harvesters must submit reports documenting harvesting activities as an integral part of permit requirements.*

[139] *Information on the current aquatic invasive species coordinator can be found on the WDNR website.*

relatively low cost as well as the ease, speed, and convenience of application. Disadvantages associated with chemical control include:

- **Unknown and/or conflicting evidence about long-term effects of chemicals on fish, fish food sources, and humans**—The U.S. Environmental Protection Agency studies aquatic plant herbicides to rule out short-term (acute) effects on humans and wildlife. Additionally, some studies also examine long-term (chronic) effects of the chemical on animals (e.g., the effects of being exposed to these herbicides for many years). However, it is often impossible to conclusively state that no long-term effects exist due to the animal testing protocol, time constraints, and other issues. Additionally, long-term studies have not addressed all potentially affected species.[140] For example, conflicting studies/opinions exist regarding the role of the chemical 2,4-D as a human carcinogen.[141] Some lake property owners judge the risk of using chemicals as being too great, despite legality of use. Consequently, the concerns of lakefront owners should be considered whenever chemical treatments are proposed. Additionally, if chemicals are used, they should be applied as early in the season as practical and possible. This helps assure that the applied chemical decomposes before swimmers and other lake users begin to actively use the lake.[142]

- **An increased risk of algal blooms**—Water borne nutrients promote growth of aquatic plants and algae. If rooted aquatic plants are not the primary user of water-borne nutrients, algae tend to be more abundant. Action must be taken to avoid both loss of native plants and excessive chemical use, which can compromise the health of a lake's native plant community and reduce the ability of rooted aquatic plants to compete with algae for limiting nutrients. Balance must be maintained between rooted aquatic plants and algae -- when the population of one declines, the other may increase in abundance to nuisance levels. In addition to decreasing competition for water-borne nutrients, the death and decomposition of aquatic plants can increase nutrient levels in lake water. Higher nutrient concentrations fuel aquatic plant and algal growth.

- **A potential increase in organic sediments, and associated anoxic conditions, can stress aquatic life and cause fish kills**—When chemicals are used to control large mats of aquatic plants, the dead plant material generally settles to the bottom of a lake and subsequently decomposes. This process leads to an accumulation of organic-rich sediment and can deplete oxygen from the water column as bacteria decompose plant remains. Stratified lakes, such as Nagawicka Lake, are particularly vulnerable to oxygen depletion, especially in summer in deeper areas of the Lake. Excessive oxygen loss can inhibit a lake's ability to support certain fish and can trigger processes that release phosphorus from bottom sediment, further increasing lake nutrient levels. These concerns emphasize the need to limit chemical control to early spring when Eurasian water milfoil has not yet formed dense mats.

- **Adverse effects on desirable aquatic organisms due to loss of native species**—Native plants, such as pondweeds, provide food and spawning habitat for fish and other wildlife. A robust and diverse native plant community is a foundational element to the overall conditions a lake needs to provide and host desirable gamefish populations since fish, and the organisms fish eat, require aquatic plants for food, shelter, and oxygen. If native plants are unintentionally lost due to insensitive herbicide application, fish and wildlife populations often suffer. Consequently, if chemical herbicides are applied to the Lake, these chemicals must preferentially target Eurasian water milfoil or curly-leaf pondweed. Such chemicals should be applied in early spring when native plants have not yet emerged.

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[140] *U.S. Environmental Protection Agency, EPA-738-F-05-002, 2,4-D* RED Facts, *June 2005.*

[141] *M.A. Ibrahim, et al., "Weight of the Evidence on the Human Carcinogenicity of 2,4-D,"* Environmental Health Perspectives *96: 213-222, 1991.*

[142] *Though the manufacturers indicate that swimming in 2,4-D-treated lakes is allowable after 24 hours, it is possible that some swimmers may want more of a wait time to ensure that they receive less exposure to the chemical. Consequently, allowing for extra time is recommended, so that residents and Lake users can feel comfortable that they are not being unduly exposed.*

- **A need for repeated treatments due to re-emergence of target plants from existing seed banks and/or plant fragments**—As mentioned previously, chemical treatment is not a one-time solution. The fact that the treated plants are not actively removed from the Lake increases the potential for viable seeds/fragments to remain after treatment, thereby allowing for resurgence of the target species the next year. Additionally, leaving large areas void of plants (both native and invasive) creates a disturbed area without an established plant community. Eurasian water milfoil thrives in disturbed areas. In summary, applying chemical herbicides to large areas can provide opportunities for re-infestation which in turn necessitates repeated herbicide applications.

- **Hybrid water milfoil's resistance to chemical treatments**—Hybrid water milfoil complicates management since research suggests that certain strains may have higher tolerance to commonly utilized aquatic herbicides such as 2,4-D and Endothall.[143,144] Consequently, further research on the efficacy and impacts of herbicides on hybrid water milfoil needs to be conducted to better understand the appropriate dosing applied within Nagawicka Lake.

As discussed previously, other factors complicate chemical herbicide application in lakes, namely, coincident growth of Eurasian water milfoil and native species, the physical similarities between native water milfoil and Eurasian water milfoil, and the presence of hybrid Eurasian water milfoil. Hybrid water milfoil has been verified to exist in Nagawicka Lake. Since Eurasian water milfoil tends to grow early in the season, *early spring* chemical application is an effective way to target the Eurasian water milfoil while minimizing impact to desirable native plants. Early spring is a subjective term that is tied to overall weather conditions, ice-off dates, the type of chemicals applied, and the plant species targeted by the application effort. With these conditions in mind, "early spring" can mean as early as April or as late as June. Early spring application has the advantage of being more effective due to the colder water temperatures, a condition enhancing herbicidal effects and reducing the dosing needed for effective treatment. Early spring treatment also reduces human exposure (swimming is not particularly popular in very early spring) and limits the potential for unintentional damage to native species.

Another factor to consider is the history of chemical treatment on Nagawicka Lake (see Table 2.24) and the ways target plants have reacted to these treatments. The first recorded chemical treatments were completed in 1950 and have continued until the present, although, since 2003, the aquatic plant control program has shifted away from chemical treatment and toward mechanical harvesting as a major element of the aquatic plant management strategy in the Lake. Some individual riparian and property owners' associations manually harvest aquatic plants around piers and docks and along their shorelines, and some have treated specific areas of the Lake with chemical herbicides.

While comparatively modest populations of Eurasian water milfoil are present in Nagawicka Lake, other plants do impede navigation. Therefore, while chemical treatment is not necessary to actively control for the current population of Eurasian water milfoil, it is a viable option for resolving navigation problems in critical areas of the Lake. Whatever the case, monitoring should continue to ensure that Eurasian water milfoil and curly-leaf populations are not allowed to spread or otherwise become more problematic. If further monitoring suggests an increase in these invasive species populations, chemical treatment should be reviewed as a management option.

Other Aquatic Plant Management Issues of Concern

Residents have been concerned over clumps of aquatic plants gathering near the outlet dam. The remnant floating aquatic plants that have not been picked up during the harvesting operation have been collecting at the outlet dam and allowing large masses of harvested plants to flow through the dam, presumably into Upper Nemahbin Lake downstream (see Figure 2.78). Greater emphasis on plant pick-up during and following harvesting can reduce the potential for spread of invasive species along the Bark River.

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[143] *L.M. Glomski, M.D. Netherland, "Response of Eurasian and Hybrid Watermilfoil to Low Use Rates and Extended Exposures of 2,4-D and Triclopyr,"* Journal of Aquatic Plant Management *48: 12-14, 2010.*

[144] *E.A. LaRue, et al., "Hybrid Watermilfoil Lineages are More Invasive and Less Sensitive to a Commonly Used Herbicide than Their Exotic Parent (Eurasian Watermilfoil),"* Evolutionary Applications *6: 462-471, 2013.*

Table 2.24
Aquatic Plant Chemical Control Agents Applied to Nagawicka Lake: 1950 – 2015

	Macrophyte Control							Algal Control		
	Glyphosate (Rodeo)	Sodium Arsenite	Diquat	Endothall		2,4-D		Cutrine Plus	Copper Sulphate	AV-70
Year	(gallons)	(pounds)	(gallons)	Gallons	Pounds	Gallons	Pounds	(gallons)	(pounds)	(gallons)
1950-58	--	17,432	--	--	--	--	--	--	--	--
1959	--	2,860	--	--	--	--	--	--	200	--
1960	--	2,100	--	--	--	--	--	--	250	--
1961	--	6,520	--	--	--	--	--	--	300	--
1962	--	5,130	--	--	--	--	--	--	400	--
1963	--	12,240	--	--	--	--	--	--	1,400	--
1964	--	11,340	--	--	--	--	--	--	2,200	--
1965	--	11,700	--	--	--	--	--	--	1,400	--
1966	--	9,702	--	--	--	--	--	--	1,440	--
1967	--	8,190	--	--	--	--	--	--	1,150	--
1968	--	--	--	--	--	--	--	--	--	--
1969	--	--	--	--	--	--	--	--	405	--
1970	--	--	--	--	--	--	--	--	1930	--
1971-73	--	--	--	--	--	--	--	--	--	--
1974	--	--	--	--	50	--	--	--	165	--
1975	--	--	--	20	--	--	--	--	2,200	35
1977	--	--	--	10	--	--	--	--	1,400	8
1978	--	--	--	10	--	--	--	--	--	12
1979	--	--	--	3	--	--	--	5.5	--	--
1980	--	--	--	6	--	--	--	9	--	--
1981	--	--	--	15	--	--	17	20	--	--
1982-83	--	--	--	--	--	--	--	--	--	--
1984	--	--	3	14	--	28	--	63	--	--
1985	--	--	24	20.5	--	3	--	33	--	--
1986	--	--	14	21.5	--	9	--	38.50	--	--
1987	3.1	--	17.25	22.5	--	--	--	18.75	--	--
1988	--	--	20	--	--	--	--	48	--	--
1989	--	--	--	3	--	31.25	--	2.25	--	--
1990	--	--	2.5	6	--	20.5	--	5.5	--	--
1991	--	--	.75	--	--	8.25	--	0.75	--	--
1992	--	--	1.75	--	--	7	--	1.75	--	--
1993	--	--	2.75	--	--	--	--	7	--	--
1994	--	--	1	--	--	--	2.5	1	--	--
1995	--	--	--	--	--	--	--	--	--	--
1996	--	--	--	--	--	8.75	--	--	--	--
1997-2015	17.28	--	--	2.0	--	--	--	--	--	--
Total	20.29	87,214	87	153.5	50	115.75	19.5	254	14,840	55

Source: Wisconsin Department of Natural Resources

Many activities can inhibit or prevent future nuisance aquatic plant growth, which, in turn, helps avoid adverse effects related to many in-lake control alternatives. A number of factors create a lake environment conducive to "excessive" plant growth, both in terms of Eurasian water milfoil and native plants. For example, poor water quality with high phosphorus content (which can result from polluted surface water runoff or from internal loading) provides the building blocks that all plants need to thrive and eventually reach what is perceived as nuisance levels. Consequently, implementing recommendations to improve water quality must be integral to any comprehensive aquatic plant management plan. This is the reason why many of the issues of concern discussed under "Water Quality" are also priorities for aquatic plant management.

Lake users should be vigilant regarding new invasive species and should proactively manage the very real threat of new species colonizing the Lake. Many additional aquatic invasive species threaten lakes but are not known to be present in Southeastern Wisconsin (e.g., hydrilla (*Hydrilla verticillata*)) or, if found in Southeastern Wisconsin, are not found in Nagawicka Lake (e.g., yellow floating heart (*Nymphoides peltata*)). Such species can cause harm to the ecology of a lake; therefore, ways to protect Nagawicka Lake against new nonnative species are discussed in Chapter 3 of this report.

2.5 RECREATION

Nagawicka Lake is a multi-purpose waterbody providing a variety of active and passive recreational uses. Active recreation includes boating, waterskiing, tubing, swimming, and fishing during the summer months, and cross-country skiing, snowmobiling, and ice fishing during the winter. The Lake is used year-round as a visual amenity to visitors and residents alike. Walking, bird watching, and picnicking are popular passive recreational uses of this waterbody. Its location, lying in the vicinity of the Lapham Peak Unit of the Kettle Moraine State Forest, and within easy travel distance from the metropolitan areas of Milwaukee and Chicago, makes this Lake a popular recreational destination.

Figure 2.78
Aquatic Plants Collecting at Dam

Source: Lake Welfare Committee and SEWRPC

Nagawicka Lake Public Access

Nagawicka Lake's public access locations are located on Map 2.35. These locations include several parks, fishing piers and boat launch sites.[145] Naga-Waukee Park, which is owned and operated by the Waukesha County Department of Parks and Land Use, is a 206-acre park (414 acres including the 18-hole golf course) that provides a public beach, campgrounds, and a paved launch facility with parking. The entrance fee for Naga-Waukee Park is currently $4.00 per car. Access to the boat launch, which is located on Mariner Drive along the southeast shore of the Lake, is $6.00 for a carry-in, $6.50 for trailered watercraft on weekdays and $8.00 for trailered watercraft on weekends. Annual passes are offered for a fee of $32.00 for adults and $16.00 for seniors. In addition to Naga-Waukee Park, there is a boat launch, operated by the City of Delafield, located on Bleeker Street on the western shoreline of the Lake near the outlet. It provides access exclusively to citizens of the City of Delafield and requires a permit from City Hall. Boat mooring for the purpose of long-term residence, sleeping, or camping is prohibited. Given what is known about the site, boat launch facilities and fees appear to conform to the maximum requirements set forth in Chapter NR 1 of the *Wisconsin Administrative Code*. Compliance with this section is important since certain grant and assistance funding is predicated by compliance with Chapter NR 1. It appears that the Town launch fees could be increased by at least $2.00.[146] Launch fees can influence the intensity of use of the launch facility and can be considered as part of a program to help avoid excess boat densities on the Lake. This is discussed in more detail in Chapter 3.

Wisconsin Boating Surveys

The type of boating taking place varies by the day of the week, time of day, and prevailing weather conditions. According to a Statewide survey that subdivided results by region,[147] boaters in Southeastern Wisconsin took to the water in the greatest numbers during July, with slightly lower numbers of boaters found on the water during June and August (Table 2.25). These months account for approximately two-thirds of the total number of boater-days logged in the Region for the entire year. About three times as many boaters use their boats on weekends than weekdays (Table 2.26).

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[145] *Maps available on the WDNR Surface Water Data Viewer also depict a canoe launch on the southwestern shore of Nagawicka Lake.*

[146] *NR 1.91(11)a encourages free boat launching but allows a maximum one-day base fee equivalent to the one-day fee for residents to enter State parks ($8.00 at the time of this report). NR1.91(11)b allows additional surcharges based upon the presence of an attendant (20 percent base fee surcharge), the size of boats served (30 percent base fee surcharge for boats between 20 and 26 feet in length and 60 percent base fee surcharge for boats greater than 26 feet in length), and the presence of on-site toilet facilities (20 percent base fee surcharge).*

[147] *Wisconsin Department of Natural Resources Technical Bulletin 174, Boating Pressure on Wisconsin's Lakes and Rivers, Results of the 1989-1990 Wisconsin Recreational Boating Study, Phase 1, 1991.*

Map 2.35
Nagawicka Lake Public Access Opportunities

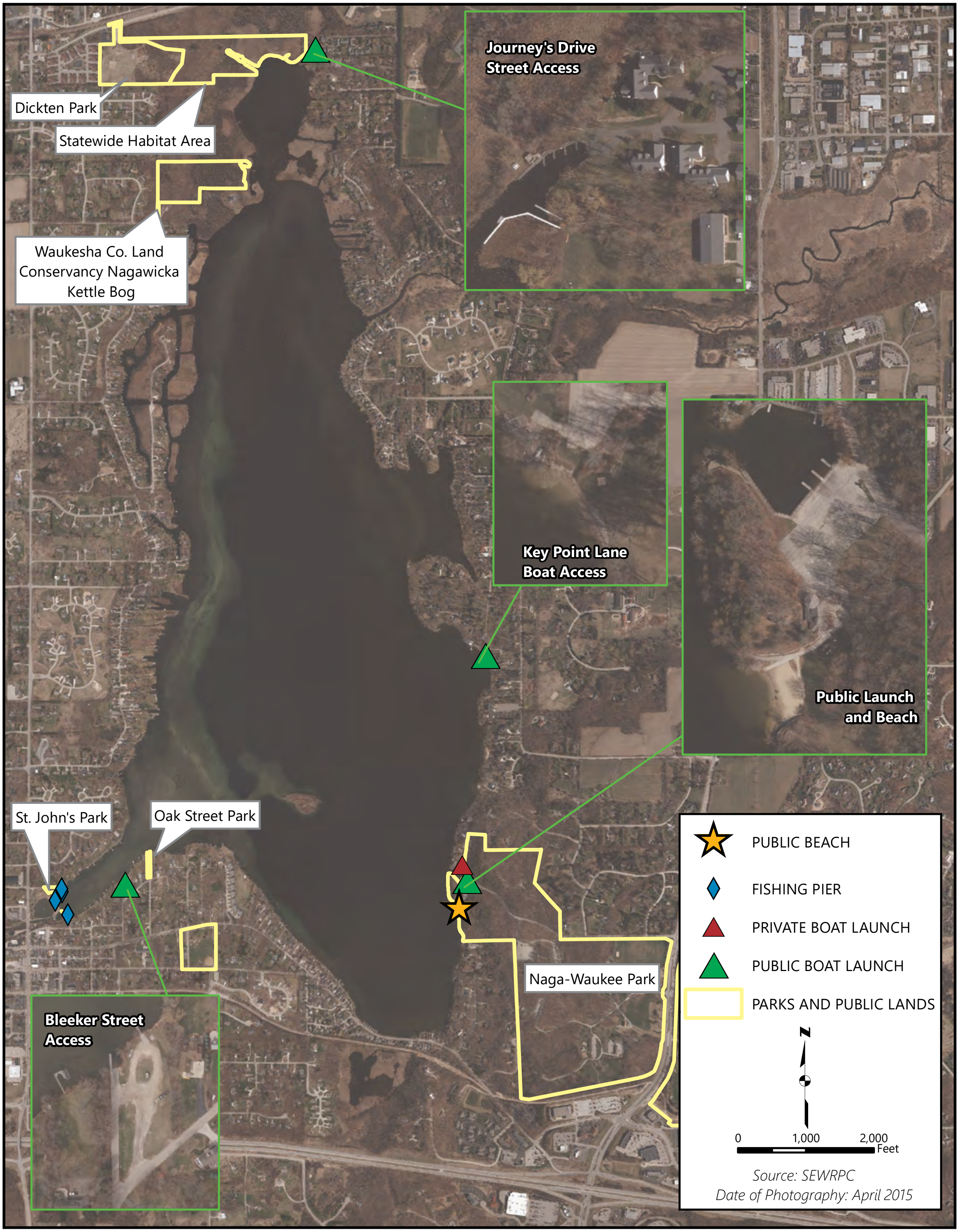


Table 2.25
Boat User Activity in the Region by Month: 1989 – 1990

	Percent Respondents Participating[a]						
Activity	April	May	June	July	August	September	October
Fishing	68	57	49	41	44	42	49
Cruising	29	39	42	46	46	47	43
Water Skiing	3	9	20	27	19	16	8
Swimming	2	4	18	31	25	19	5
Average boating party size: 3.4 people							

[a] *Respondents may have participated in more than one activity.*

Source: Wisconsin Department of Natural Resources

Fishing was the most popular activity in Southeastern Wisconsin in both spring and fall and remains a leading reason for boat use throughout the summer (Table 2.25). The typical boat used on inland lakes in Southeastern Wisconsin is an open hulled vessel measuring approximately 18 feet long, powered by a motor producing approximately 90 horsepower (Tables 2.27 and 2.28). Sailboats comprise approximately 24 percent of boat traffic (15 percent non-powered and 9 percent unpowered), while other unpowered boats comprise only two percent of boats found on waterbodies in the Region.

Boat Counts on Nagawicka Lake

The types of watercraft docked or moored on a lake, as well as the relative proportion of non-motorized to motorized watercraft, reflect the interests of the primary lake users (i.e., riparian landowners). To help characterize recreational use of Nagawicka Lake, Commission staff completed a watercraft census (i.e., a count of boats along the Lake's shoreline) during summer 2016. At the time of the survey, 1,246 boats were observed either moored in the water or stored in the shoreland areas around Nagawicka Lake (Table 2.29). This is an increase of 196 watercraft from a census completed by Commission staff in 2002.[148] However, kayaks were not included in the 2002 census. Considering that 151 kayaks were counted in 2016, it is possible that a similar number of kayaks were present in 2002 and that the number of watercrafts around Nagawicka Lake has remained essentially unchanged. About 21 percent of all docked or moored boats were motorized, with pontoon boats, power boats, and personal watercraft being the most common types. Of the non-motorized watercraft observed, kayaks, canoes, and sailboats were most common. To assess the degree of recreational boating use of a lake, it has been estimated that, in southeastern Wisconsin, the number of watercraft operating at any given time is 2 to 5 percent of the total number of watercraft docked and moored. On Nagawicka Lake, this would translate to about 25 to 60 boats in use on the Lake.

Another way to assess the degree of recreational boat use on a lake is through direct counts of boats actually in use on a lake at a given point in time. The types of watercraft in use on Nagawicka Lake during typical summer weekdays and weekends were inventoried in the field by Commission staff during summer 2016. The results of these surveys are shown in Table 2.30. These data demonstrate that boat traffic is much heavier during weekends, and that the types of boats in use differ dramatically with time of the day and day of the week. For example, sail boating was the most popular boating activity observed during weekend mornings while powerboating was the most popular activity on weekend afternoons, whereas fishing was more popular during weekdays. Kayaks and canoes were also popular types of watercraft in use, with midday being an especially popular time for kayaking.

Only a few respondents to the WDNR boating survey felt that excessive boat traffic was present on Southeastern Wisconsin lakes.[149] Data produced by the Commission's boat count on Nagawicka Lake corresponds quite well with regional averages, suggesting that Nagawicka Lake boating activity is typical for Region.

[148] *SEWRPC Memorandum Report No. 161, An Aquatic Plant Management Plan for Nagawicka Lake, Waukesha County, Wisconsin, March 2006.*

[149] *Wisconsin Department of Natural Resources Technical Bulletin 174, op. cit.*

Boating Pressure on Nagawicka Lake

A study completed in Michigan attempted to quantify desirable levels of boat traffic on an array of lakes used for a variety of purposes. That study concluded that 10 to 15 acres of useable lake area provides a reasonable and conservative average maximum desirable boating density, and covers a wide variety of boat types, recreational uses, and lake characteristics.[150] Use rates above this threshold are considered to negatively influence public safety, environmental conditions, and the ability of a lake to host a variety of recreational pursuits. High-speed watercraft require more space, necessitating boat densities less than the low end of the range. The suggested density for a particular lake is:

Minimum desirable acreage per boat = 10 acres + (5 acres x (high-speed boat count/total boat count))

The Commission's watercraft survey demonstrates that highest boat use on the Lake occurs during weekends. Approximately 30 to 50 percent of boats in use during peak periods were capable of high-speed operation. Given this range, the formula presented above suggests that 11.5 to 12.5 acres of useable open water should be available per boat on the lake.[151] Given that roughly 686 useable acres are available for boating in Nagawicka Lake, no more than 55 to 60 boats should be present on the lake at any one time to avoid use problems. The density of boats actually observed on Nagawicka Lake is usually less than the maximum optimal density. However, the boat inventory reveals that this density is exceeded on summer weekends creating the potential for use conflict, safety concerns, and ecological degradation.

Boater Movement

The WDNR has collected survey data regarding lakes that visited up to five days before and after traveling to Nagawicka Lake through the Clean Boats, Clean Waters program (see Figures 2.79 and 2.80, respectively).[152] Visitors to Nagawicka Lake had traveled to 33 other waterbodies in Wisconsin within five days before coming to Nagawicka and traveled to 11 other waterbodies within five days after visiting Nagawicka. Visitors to the Lake had traveled to lakes across Wisconsin, indicating the ability for the Lake to draw visitors from the entire state. However, this also showcases the potential spread of aquatic invasive species that are present in other parts of Wisconsin. In addition, these data show that there is substantial traffic among the lakes in Waukesha County, highlighting the potential for spread of novel invasive species, such as starry stonewort, throughout the region.

Table 2.26
Day-of-the-Week Boat Use in the Region: 1989 – 1990

Day of the Week	Percent Respondents Participating[a]
Sunday	46
Monday	16
Tuesday	14
Wednesday	16
Thursday	13
Friday	17
Saturday	46

[a] *Respondents may have participated in more than one day.*

Source: Wisconsin Department of Natural Resources

Table 2.27
Boat Hull Types in the Region: 1989 – 1990

Hull Type	Percent Respondents Participating[a]
Open	68
Cabin	17
Pontoon	9
Other	6
Average length: 18.4 feet	
Average beam width: 6.4 feet	

[a] *Respondents may have participated in more than one day.*

Source: Wisconsin Department of Natural Resources

Table 2.28
Propulsion Types in the Region: 1989 – 1990

Propulsion Type	Percent Respondents Participating[a]
Outboard	53
Inboard/Outboard	14
Inboard	6
Other (powered)	1
Sail	15
Sail with Power	9
Other (nonpowered)	2
Average horse power: 86.5	

[a] *Respondents may have participated in more than one day.*

Source: Wisconsin Department of Natural Resources

[150] *Progressive AE, Four Township Recreational Carrying Capacity Study, Pine Lake, Upper Crooked Lake, Gull Lake, Sherman Lake, Study prepared for Four Township Water Resources Council, Inc. and the Townships of Prairieville, Barry, Richland, and Ross, May 2001.*

[151] *Useable lake area is the size of the open water area that is at least 100 feet from the shoreline.*

[152] *dnrmaps.wi.gov/H5/?viewer=Lakes_AIS_Viewer.*

Recreational Activities in/on Nagawicka Lake

Commission staff inventoried the activities that Lake users were participating in during select time periods of summer 2016 (see Table 2.31). The most popular recreational activities, both during the week and on the weekends, included pleasure boating, swimming, fishing from boats, and sailing. Visiting Naga-Waukee Park also was a popular activity. Participation has increased in all boating activities since the 2002 survey.[153] However, it appears that pleasure boating has increased significantly both on weekends and weekdays. The 2002 survey indicated weekend and weekday pleasure boating accounted for 13 and 15 percent of participants, respectively. In 2016, weekend and weekday pleasure boating accounted for 42 and 37 percent of participants, respectively. On a relative basis, nonboating activities (e.g., swimming, park-going) were much less popular in 2016 compared to 2002. Approximately 60 percent in the 2002 survey of people were engaged in nonboating activities in 2002 compared to only approximately 30 percent of all participants in 2016.

Table 2.29
Watercraft Docked or Moored on Nagawicka Lake: 2016

Type of Watercraft	Watercrafts Observed
Powerboat	263
Fishing Boat	46
Pontoon Boat	317
Personal Watercraft	168
Canoe	103
Sailboat	89
Kayak	151
Paddle Boat	53
Row Boat	54
Total	1,246

[a] *Includes trailered watercraft and watercraft on land observable during survey.*

Source: SEWRPC

Boating and In-Lake Ordinances

Boating and other in-lake ordinances regulate the use of the Lake in general, and, when properly implemented and enforced, can help prevent safety issues, use conflict situations, and inadvertent damage to the Lake. Examples of such concerns includes excessive noise, inappropriate use and/or use timing, wildlife disturbance, navigational hazards, shoreline erosion from excessive artificially induced wave action, and agitation of sediment and aquatic vegetation in shallow areas. Controls on boat traffic are currently set forth in *Chapter 19, Parks and Public Waters*, of the City of Delafield Code of Ordinances, and include a 25-mph speed limit restriction during increased Lake use in June, July, and August.[154] These ordinances are generally enforced by a WDNR warden, the Delafield Water Safety Patrol Unit, or by a local law enforcement agency.

2.6 FISH AND WILDLIFE

Healthy fish, bird, amphibian, reptile, and mammal populations require good water quality, sufficient water level/flow volumes, healthy aquatic and terrestrial plant populations and species mixes, access to life-cycle critical habitat, and well preserved or maintained aquatic and terrestrial habitat. Wildlife populations can be maintained or even enhanced by implementing "best management practices" (BMPs). Since water supply maintenance, water quality enhancement and aquatic plant management (all of which help maintain or enhance wildlife populations) have been discussed previously in this chapter, this section focuses on issues that help maintain and expand habitat, allow key management decisions to be made, and using BMPs and targeted strategies to enhance aquatic and terrestrial wildlife populations.

Fishery Management Practices

Fishery management practices can be implemented by homeowners, recreationalists, and resource managers. Such activities include catch and release angling and fish habitat enhancement, both of which help improve a lake's overall fishery. To determine the most needed and effective practices, it is important to consider each of the following.

- **The population and size structure of the fish species present in a lake**—Studies that examine the species, populations, and size structure of fish in a lake help managers understand issues that may face fish populations. For example, if low numbers of juvenile fish of a certain species are

[153] *SEWRPC Memorandum Report No. 161,* An Aquatic Plant Management Plan for Nagawicka Lake, Waukesha County, Wisconsin, *March 2006.*

[154] *Chapter 19, Parks and Public Waters and other City of Delafield ordinances can be found at: library.municode.com/wi/delafield/codes/code_of_ordinances.*

Table 2.30
Watercraft in Use on Nagawicka Lake: 2016

	Weekend Activity Survey					
	Visit 1 (July 10th) 8:00 a.m. to 10:00 a.m.		Visit 2 (August 14th) 12:00 p.m. to 2:00 p.m.		Total	
Type of Activity	Count	Percent	Count	Percent	Count	Percent
Canoeing and Paddle Boating	3	2.4	0	0.0	0	0.0
Fishing from Boats	4	3.2	9	81.8	9	10.6
Fishing from Shoreline	0	0.0	1	9.1	1	1.2
Operating Personal Watercraft	5	4.0	0	0.0	2	2.4
Park Goers	35	27.8	0	0.0	12	14.1
Pleasure Boating	37	29.4	1	9.1	42	49.4
Sailing	10	7.9	0	0.0	12	14.1
Skiing/ Tubing	15	11.9	0	0.0	4	4.7
Swimming	17	13.5	0	0.0	4	4.7
Total	126	100.0	11	100.0	85	100.0

	Weekday Activity Survey							
	Visit 1 (June 24th) 12:00 p.m. to 2:00 p.m.		Visit 2 (July 8th) 6:00 a.m. to 8:00 a.m.		Visit 3 (August 8th) 4:00 p.m. to 6:00 p.m.		Total	
Type of Watercraft	Count	Percent	Count	Percent	Count	Percent	Count	Percent
Canoeing and Paddle Boating	3	2.4	0	0.0	0	0.0	3	1.4
Fishing from Boats	4	3.2	9	81.8	9	10.6	22	9.9
Fishing from Shoreline	0	0.0	1	9.1	1	1.2	2	0.9
Operating Personal Watercraft	5	4.0	0	0.0	2	2.4	7	3.2
Park Goers	35	27.8	0	0.0	12	14.1	47	21.2
Pleasure Boating	37	29.4	1	9.1	42	49.4	80	36.0
Sailing	10	7.9	0	0.0	12	14.1	22	9.9
Skiing/ Tubing	15	11.9	0	0.0	4	4.7	19	8.6
Swimming	17	13.5	0	0.0	4	4.7	21	9.5
Total	126	100.0	11	100.0	85	100.0	222	100.0

Note: Activity counts were done in 2016:

Source: SEWRPC

found, this may suggest that this fish species is not successfully reproducing in the lake. In such a situation, if the desire is to promote a self-sustaining population of this fish species, species-specific spawning and rearing habitat may need to be made more accessible, restored, or created. Similarly, if abundant juveniles are found with few large fish, over-fishing may be a factor limiting the maturation of fish, thereby suggesting that catch and release should be promoted in the lake. This type of information can help lake managers target specific fish population enhancement efforts efficiently and effectively.

- **Native fish species and the history of fish stocking in a lake**—To evaluate extant fish populations, it is important to know the number, size, and species of fish introduced through stocking. For example, if only large stocked fish exist in a lake, it is likely that little to no effective natural reproduction occurs which in turn means that the lake's fishery is highly dependent on fish stocking. This may suggest that enhanced or artificial spawning and rearing areas can add value to the lake's fishery.

The WDNR reports that largemouth bass (*Micropterus salmoides*) are considered "common" in Nagawicka Lake, while various panfish, smallmouth bass (*Micropterus dolomieu*), northern pike (*Esox lucius*), and walleye pike (*Sander vitreus*) are "present."[155] The WDNR completed a fishery survey during spring 2010 that relied upon netting and electrofishing.[156] This study found the following species present in the lake at various

[155] *More information can be found on the WDNR Nagawicka Lake Page: dnr.wi.gov/lakes/lakepages/LakeDetail.aspx?wbic=828000.*

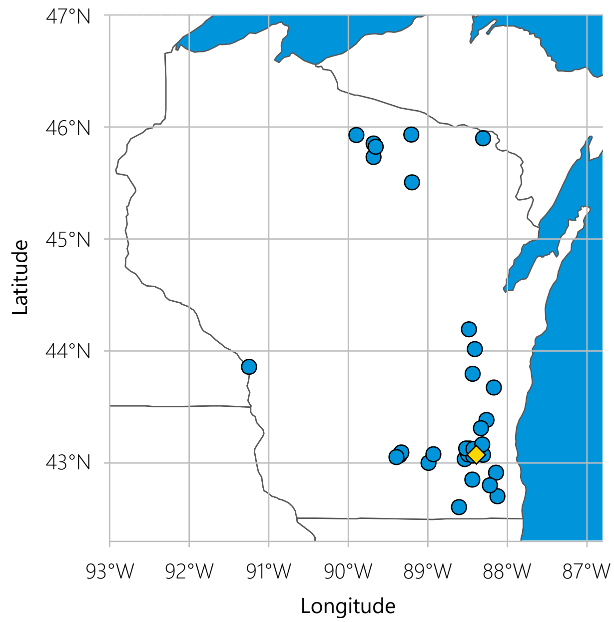
[156] *B. Heussner, S. Gospodarek, and A. Notbohm (WDNR),* Comprehensive Survey Report of Nagawicka Lake – Waukesha County, *August 13, 2013.*

levels of abundance, age, and size: walleye pike, northern pike, smallmouth bass, largemouth bass, bluegill (*Lepomis macrochirus*), rock bass (*Ambloplites rupestris*), yellow perch (*Perca flavescens*), black crappie (*Pomoxis nigromaculatus*), pumpkinseed (*Lepomis gibbosus*), bowfin (*Amia calva*), yellow bullhead (*Ictalurus natalis)*, and lake chubsucker (*Erimyzon sucetta,* a Wisconsin listed species of special concern). A few invasive common carp (*Cyprinus carpio*) were also found, but carp are not considered to be a management concern in this fishery. The WDNR again sampled fish in the Lake during 2017, but the results of this study are not yet available.

Many recommendations were made by the WDNR as part of the most recent published fishery evaluation. These recommendations included the following recommended actions.

- Transition to a more restrictive length and bag limit for walleye to extend protection of female walleyes for multiple spawning seasons. This could potentially increase the contribution of natural recruitment to the walleye population.
- Convert from stocking small fingerling to large fingerling walleyes to increase survival and overall adult abundance.
- Monitor walleye population for contribution of stocked versus naturally reproduced fish to each year class.
- Continue regular stocking of large fingerling northern pike to increase survival and improve overall abundance.
- With high mortality rates above the 26-inch minimum size limit, restrict angler harvest to one northern pike per day with a 32-inch minimum length limit.
- Continue to monitor bass and panfish populations through catch rates, average sizes, and abundance estimates.
- Monitor white sucker population and spawning success because of their importance as a gamefish forage species.
- Protect and improve habitat and water quality to promote diverse and healthy fish communities.

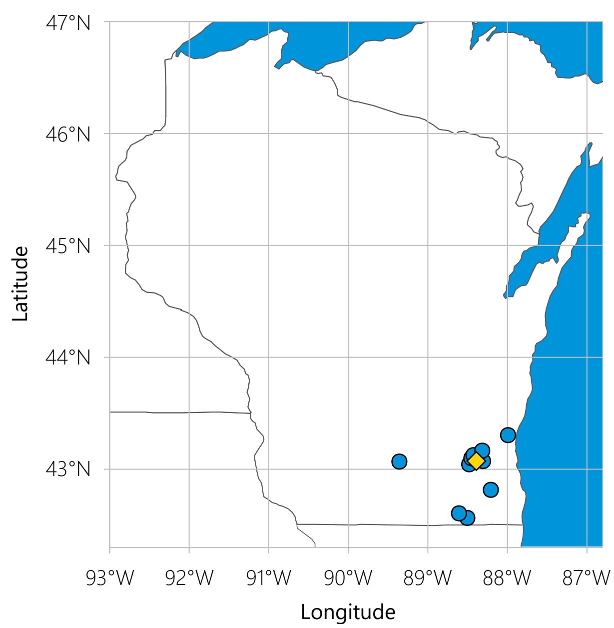
Figure 2.79
Waterbodies that Boaters Visited Before Visiting Nagawicka Lake



Note: Diamond indicates location of Nagawicka Lake.

Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 2.80
Waterbodies that Boaters Visited After Visiting Nagawicka Lake



Note: Diamond indicates location of Nagawicka Lake.

Source: Wisconsin Department of Natural Resources and SEWRPC

Table 2.31
Nagawicka Lake Recreational Use Inventory: 2016

	Number of Watercraft Types: Weekend Survey					
	Visit 1 (July 10th) 8:00 a.m. to 10:00 a.m.		Visit 2 (August 14th) 12:00 p.m. to 2:00 p.m.		Total	
Type of Watercraft	Count	Percent	Count	Percent	Count	Percent
Canoe/Kayak	0	0.0	6	6.4	6	4.3
Fishing Boat	3	6.7	2	2.1	5	3.6
Paddle Boat	0	0.0	0	0.0	0	0.0
Personal Watercraft	0	0.0	4	4.3	4	2.9
Pontoon Boat	3	6.7	22	23.4	25	18.0
Powerboat	11	24.4	59	62.8	70	50.4
Sailboat/Wind Board	28	62.2	1	1.1	29	20.9
Total	45	100.0	94	100.0	139	100.0

	Number of Watercraft Types: Weekday Survey							
	Visit 1 (June 24th) 12:00 p.m. to 2:00 p.m.		Visit 2 (July 8th) 6:00 a.m. to 8:00 a.m.		Visit 3 (August 8th) 4:00 p.m. to 6:00 p.m.		Total	
Type of Watercraft	Count	Percent	Count	Percent	Count	Percent	Count	Percent
Canoe/Kayak	3	10.7	0	0.0	0	0.0	3	10.7
Fishing Boat	3	10.7	6	85.7	8	28.6	3	10.7
Paddle Boat	0	0.0	0	0.0	0	0.0	0	0.0
Personal Watercraft	2	7.1	0	0.0	2	7.1	2	7.1
Pontoon Boat	3	10.7	0	0.0	6	21.4	3	10.7
Powerboat	12	42.9	0	0.0	6	21.4	12	42.9
Sailboat/Wind Board	5	17.9	1	14.3	6	21.4	5	17.9
Total	28	100.0	7	100.0	28	100.0	28	100.0

Note: Boat counts were done in 2016.

Source: SEWRPC

White suckers are a vital foundation part of the Lake's fishery,[157] supporting the population of popular gamefish such as the walleye, northern pike, and bass. White suckers spawn in rocky streams and depend entirely on unfettered access to the Lake's only significant perennial tributary—the Upper Bark River. Without access to this stream, or in the event of water quality or habitat degradation in this stream, white sucker abundance would radically decline, and with it, the population of popular gamefish.

In addition to suckers, many native fish will migrate for long distances upstream during spawning migrations to find habitat suitable for spawning and rearing of newly hatched fish. For example, smallmouth bass are known to migrate 60 miles, walleye have been observed to migrate 150 miles, and northern pike migrate up to 200 miles. Therefore, maintaining and enhancing the ability for fish to migrate from the Lake to upstream reaches of the River is vital for overall gamefish abundance and health. Actions that improve the ability for fish to expend less energy to access suitable habitat and/or that increase the quantity of accessible suitable habitat have the potential to increase the abundance, health, size, and sustainability of both forage fish and gamefish. Such action should include manipulating structures that do not produce complete fish passage barriers.[158]

[157] *Heussner, 2013,* op. cit.

[158] *Some fish barriers are easy to identify (e.g., dams, cascading culvert outfalls) while other are not immediately evident without intimate knowledge of fish swimming performance and fish behavior. Examples of such features include structures that pass water at excessive velocity only during the high-water periods which favor fish migration, excessively long structures, and portions of streams that cease flowing above the bed during dry periods which can prevent downstream migration of juvenile fish.*

Nagawicka Lake has been intermittently stocked by public agencies for over 110 years. For example, during 1899, 560,000 walleye fry were planted into Nagawicka Lake.[159] Furthermore, at least 15,000 brook trout were planted into the Bark River watershed in the vicinity of the Village Hartland between 1891 and 1892.[160] Nagawicka Lake has regularly been stocked with northern pike and walleye since 1981 (see Table 2.32). In addition, Nagawicka Lake was identified by WDNR as a good candidate for walleye stocking under the Wisconsin Walleye Initiative,[161] a program designed to help improve walleye populations and the success of natural reproduction across Wisconsin.

Nagawicka Lake and other large, deep lakes in the immediate vicinity are biologically unique. Many of these deep lakes naturally host or formerly hosted cisco (*Coregonus artedi*), a fish sometimes also known as lake herring. Cisco require cold water during summer months, retreating to well-oxygenated deep-water areas. These conditions only occur in deep lakes with high water quality; lakes that harbor these conditions are known as "two-story" lakes (see Figure 2.81). Unfortunately, this fish persists in only a handful of Waukesha County lakes (Fowler, North, Oconomowoc, Okauchee, and Pine Lakes).[162] However, it was once widespread in Waukesha County, and was also formerly found in Lac La Belle, Nagawicka, Upper and Lower Nashotah, Upper Nemahbin, Golden, and Dutchman Lakes.[163]

The WDNR still classifies Nagawicka as a two-story lake, even though the conditions supporting this desirable classification are severely compromised.[164] Even though cisco formerly inhabited the Lake, heavy nutrient loads formerly delivered to the Lake caused conditions that depleted oxygen in the cold, deep habitat necessary for cisco survival. With the loss of oxygen in this refuge area, cisco could no longer persist in the Lake. Similar conditions likely eliminated cisco from downstream lakes, a situation preventing natural restocking.

It is important to note that Nagawicka Lake still cannot yet support adult ciscoes based upon an analysis of the Lake's oxythermal conditions as shown in Figure 2.82. The dashed red line in Figure 2.82 depicts the parametrically fitted lethal niche boundary for adult ciscoes, which clearly shows that there are often frequent lethal combinations of temperature and oxygen concentrations (all points to the right and below the dashed red line) in both summer and fall time periods. However, temperature and oxygen concentrations within Nagawicka Lake have recently improved, and if this trend continues, cisco could possibly once again successfully survive and reproduce in the Lake. Cisco would add another component to the winter fishery and would fill a vacant ecological niche enhancing the Lake's forage fish base without competing for resources with fish already present in the Lake. This generally benefits popular fish-eating gamefish, such as walleye, which are most abundant in two-story lakes.[165] Continued water quality improvement initiatives may expand and solidify potential habitat. Efforts should be made to reintroduce this native fish to the Lake.

Aquatic Habitat Enhancement

Aquatic habitat enhancement generally refers to encouraging native aquatic plant (particularly pondweed) growth within a lake, as these plants provide superior food, shelter, and spawning areas for fish. Additionally, aquatic habitat enhancement also involves protecting wetlands (see "Terrestrial Habitat Enhancement" subsection), maintaining good ecological connectivity between a lake and the rivers, streams, ephemeral

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[159] *Democrat Printing Company, State Printer,* Biennial Report of the Commissioners of Fisheries of Wisconsin for the Years 1899 and 1900*, Madison, Wisconsin, 1901.*

[160] *Democrat Printing Company, State Printer,* Fourteenth (Fifth Biennial) Report of the Commissioners of Fisheries of the State of Wisconsin 1891-1892*, Madison, Wisconsin, 1898.*

[161] *The Wisconsin Walleye Initiative was developed by the Wisconsin Department of Natural Resources and the Wisconsin Governor's office. For more information and progress updates:* dnr.wi.gov/topic/fishing/outreach/walleyeinitiative.html.

[162] *J. Lyons, J. Kampa, T. Parks, and G. Sass,* The Whitefishes of Wisconsin's Inland Lakes: The 2011-2014 Wisconsin Department of Natural Resources Cisco and Lake Whitefish Survey*, Fisheries and Aquatic Research Section, Wisconsin Department of Natural Resources, February 2015.*

[163] *A.R. Cahn, "An Ecological Study of Southern Wisconsin Fishes,"* Illinois Biological Monographs *11(1), 1927.*

[164] *NR 102.06(2)(i) defines a "stratified two-story fishery lake" as a "stratified lake which has supposed a cold water fishery in its lower depths within the last 50 years."*

[165] *Rypel, Andrew L., Timothy D. Simonson, Dniel L. Oele, Joanna D.T. Griffin, Timothy P. Parks, David Seibel, Craig M. Rovers, Scott Toshner, Lori S. Tate, and John Lyons,* Flexible Classification of Wisconsin Lakes for Improved Fisheries Conservation and Management, *Fisheries, Volume 44, Issue 5, May 2019.*

Table 2.32
Nagawicka Lake WDNR Fish Stocking Records: 1981 – 2017

Year	Species Stocked	Number Stocked	Size	Average Length (Inches)
1981	Walleye	2,000,000	Fry	--
1982	Walleye	40,000	Fingerling	2.00
1984	Walleye	42,140	Fingerling	3.00
1985	Walleye	14,400	Fingerling	4.00
1986	Walleye	50,000	Fingerling	3.00
1988	Northern Pike	40,000	Fry	3.00
1989	Northern Pike	554,000	Fry	1.00
1989	Walleye	51,745	Fingerling	2.50
1990	Walleye	48,900	Fingerling	2.00
1991	Walleye	32,221	Fingerling	3.00
1991	Northern Pike	2,000	Fingerling	8.00
1992	Northern Pike	6,290	Fingerling	8.33
1992	Walleye	46,500	Fingerling	2.00
1993	Northern Pike	5,092	Fingerling	8.30
1994	Walleye	62,378	Fingerling	2.80
1996	Walleye	49,850	Fingerling	1.60
1998	Walleye	91,368	Small Fingerling	2.70
1998	Northern Pike	4,400	Small Fingerling	--
2000	Walleye	91,711	Small Fingerling	1.70
2000	Northern Pike	4,904	Small Fingerling	3.45
2001	Northern Pike	4,252	Small Fingerling	7.20
2002	Walleye	46,200	Small Fingerling	1.90
2002	Northern Pike	2,586	Small Fingerling	3.10
2003	Walleye	46,248	Small Fingerling	1.40
2004	Walleye	76,662	Small Fingerling	1.40
2005	Northern Pike	2,500	Small Fingerling	3.00
2006	Walleye	33,563	Small Fingerling	1.40
2006	Northern Pike	5,365	Small Fingerling	2.40
2008	Northern Pike	2,000	Large Fingerling	7.00
2008	Walleye	32,095	Small Fingerling	1.60
2009	Northern Pike	619	Large Fingerling	7.50
2010	Walleye	31,110	Small Fingerling	1.47
2010	Northern Pike	3,582	Large Fingerling	7.80
2012	Northern Pike	1,962	Large Fingerling	7.90
2012	Walleye	32,095	Small Fingerling	1.37
2013	Walleye	5,428	Large Fingerling	5.25
2016	Northern Pike	2,157	Large Fingerling	8.60
2017	Walleye	4,913	Large Fingerling	6.44
2017	Northern Pike	1,764	Large Fingerling	9.45

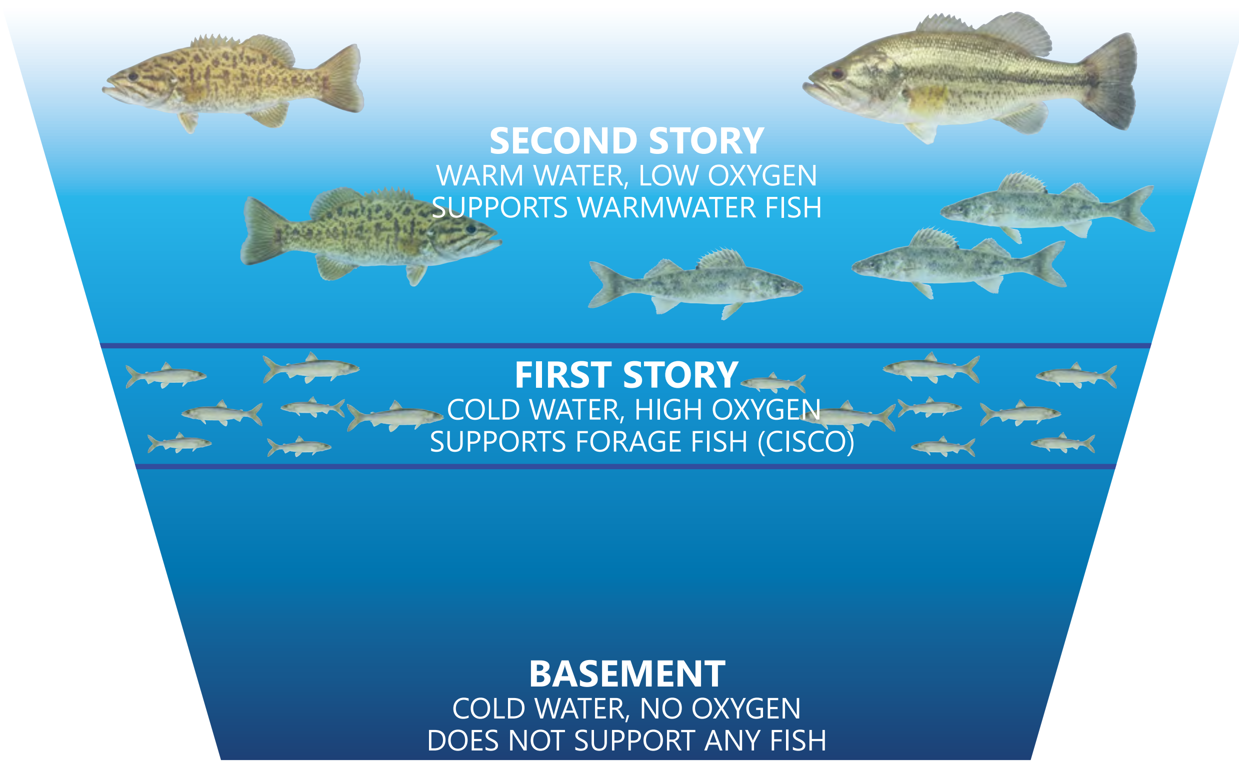
Source: Wisconsin Department of Natural Resources

creeks, and wetlands in its watershed, and encouraging the presence of coarse woody structure along shorelines. Coarse woody structure is generally abundant in unaltered natural environments, provides shelter for fish populations, acts as basking and rest areas for herptiles (e.g., frogs and turtles), may provide perch areas for important birds and insects, can help anchor valuable stream bed materials, and can also help protect shorelines from erosion in some instances.

To determine the state of the aquatic habitat within the Lake in the summer of 2016, Commission staff completed an aquatic plant survey (see Section 2.4, "Aquatic Plant Management"), and the beds, banks, and nearshore areas of local waterbodies (see Section 2.3, "Nearshore and Stream Channel Inventory").[166] The aquatic plant survey revealed that Nagawicka Lake has a highly diverse aquatic plant community. This is a good indication of a healthy, well balanced, ecologically resilient lake Nearshore and stream channel

[166] *Pondweed species are significant in a lake because they serve as excellent habitat for providing food and shelter to many aquatic organisms.*

Figure 2.81
Two-Story Lake Illustration



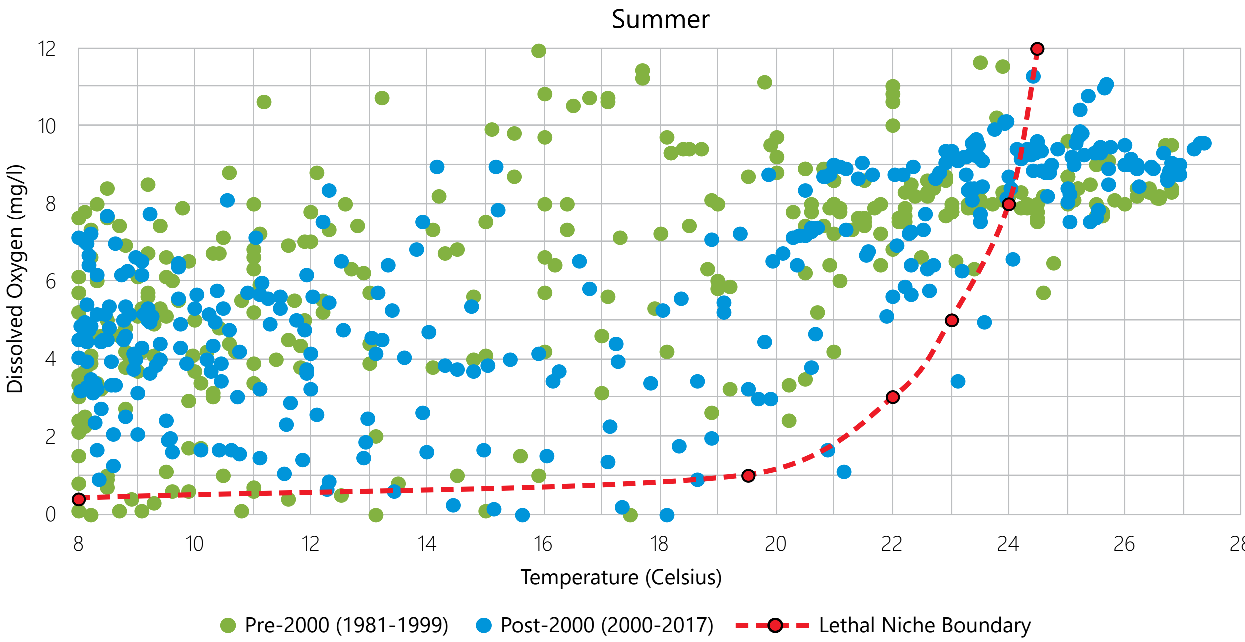
Note: This graphic illustrates a functioning "two-story" fishery, where a band of deep, cold, and oxygenated water supports a population of cisco (*Coregonus artedi*). Cisco are a forage fish that support more abundant populations of fish eating gamefish, such as walleye. Reduced dissolved oxygen concentrations in deep water, caused by poor water quality, can shrink the habitat available to cisco, eventually causing total loss of the cisco population within a lake.

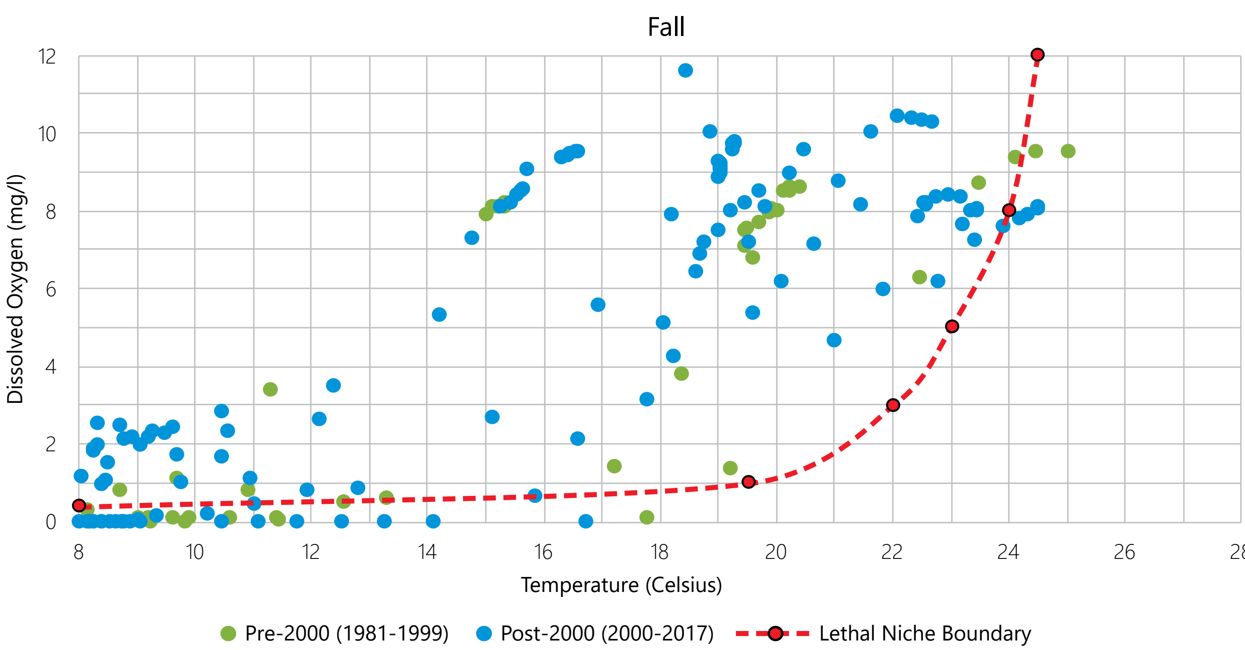
assessments revealed that Nagawicka Lake and the Bark River downstream of Merton Millpond have some areas of erosion and unprotected areas along its shoreline, and sparse areas of coarse woody structure exist. Recommendations related to these findings are discussed in Chapter 3.

Healthy aquatic ecosystems rely upon a diverse variety of habitat and substrate. For example, fish spawning, rearing, refuge, and feeding commonly take place in very different environments. The WDNR describes the bottom substrates of Nagawicka Lake as 60 percent gravel and 40 percent muck (generally a mixture of organic debris and silt). Substrate composition in shallower portions of the Lake was also noted as part of the Commission's 2016 aquatic plant survey. In the portions of Nagawicka Lake less than 15 feet deep, muck was the most predominant substrate, accounting for 53 percent of the points sampled, sand was found at 45 percent of the sampled points, and rock or gravel was found at 2 percent of the points sampled. Sand and gravel were primarily found scattered along the shorelines of Nagawicka Lake, most likely placed by property owners to augment their shorelines and reduce aquatic plant growth.

The Commission's on-the-water inventory of the Bark River downstream of Merton Millpond concluded that most of the River was underlain by coarse-grained granular bed materials. In channel deposits of clean sand, gravel, and cobbles are needed by lithophyllic spawners to support naturally reproducing fish populations. An example of an important lithophyllic spawner that frequents the Bark River is white sucker, a foundational prey species for Nagawicka Lake's popular gamefish species. Some of Nagawicka Lake's gamefish (e.g., walleye, northern pike) may also spawn in and along the Bark River downstream of Merton Millpond. Protecting valuable coarse-grained granular substrate, riparian wetlands, and seasonally flooded areas in this area helps support naturally reproducing gamefish populations in the Lake.

Figure 2.82
Combinations of Oxygen Concentrations and Temperature in Nagawicka Lake Among Critical Summer and Fall Seasons and Pre-2000 (1981 – 1999) Versus Post-2000 (2000 – 2017) Time Periods





Note: The dashed red line depicts the parametrically fitted lethal niche boundary for adult Ciscoes (Coregonus artedi). Only profile data less than 70 feet deep for dissolved oxygen and temperatures were used in this graphic.

Source: Adapted from Peter C. Jacobson, Thomas S. Jones, Pat Rivers, and Donald L. Pereira, "Field Estimation of a Lethal Oxythermal Niche Boundary for Adult Ciscoes in Minnesota Lakes", Transactions of the American Fisheries Society 137: 1464-1474, 2008; Wisconsin Department of Natural Resources; and, SEWRPC

Terrestrial Best Management Practices

The way landowners manage their own properties and understand and empathize with the needs of naturally occurring plants and animals significantly affects terrestrial wildlife populations. Turtles, for example, often travel long distances from their home lake or stream to lay eggs. If pathways to acceptable habitats are unavailable, or are dangerous due to pets, fences, or traffic, turtle populations will likely decline. Many conservation organizations have developed BMPs or behaviors that homeowners and land managers can embrace to help sustain, or even increase, wildlife populations.

Although some BMPs are species- or animal-type specific (e.g., spaying or neutering cats to limit feral cat populations, thereby reducing the desire to kill birds) many can benefit all wildlife. In general, BMPs for wildlife enhancement target either agricultural or residential lands. Agricultural measures tend to focus on encouraging land management that enhances habitat value such as allowing fallen trees to naturally decompose where practical allowing for uneven topography in certain landscapes (which creates microhabitats needed by certain plants and animals to persist and procreate) or retiring/naturalizing marginal cropland. In contrast, residential measures tend to focus on practices owners of smaller parcels can initiate that provide habitat, enhance water quality, enhance aesthetics, and/or maintain natural communities. Examples include installing rain gardens, de-emphasizing finish mowing and careful grooming of critical areas, avoiding heavy applications of fertilizers and pesticides, landscaping plans that provide food and cover for native species, and avoiding introduction and or spread of nonnative plants and animals. Certain recommendations are generally applicable to all landowners, regardless of land use. For example, indiscriminately or carelessly killing native plans and wildlife, particularly rare and sensitive plants, amphibians, reptiles, and birds, is highly discouraged.

Actively communicating BMPs to the public is an excellent means to protect and even enhance of natural plants and animals and is an activity that provides great leverage to public funding. Concepts to promote such activities are discussed further in Chapter 3.

Terrestrial Habitat Enhancement

To remain viable in the long term, terrestrial wildlife populations commonly need relatively large, well-connected areas of suitable, varied natural habitat. Consequently, protecting, connecting, enhancing, and expanding natural habitat areas are crucial planning elements to maintain and enhance wildlife diversity and abundance. Open space natural areas can generally be classified as either wetlands or uplands, as described in the following text:

- **Wetlands**—Wetlands are defined based on hydrology, hydric soils, and the presence of wetland plants. There are many types of wetlands (Figure 2.83), ranging from the familiar cattail/bulrush wetland to forested wetlands to features with unique characteristics such as calcareous fens. Most aquatic and terrestrial wildlife populations rely upon, or is associated with, wetlands for at least a part of their life cycles. This includes crustaceans, mollusks, aquatic insects, fish, amphibians, reptiles, mammals (e.g., deer, muskrats, and beavers), and various bird species, (e.g., resident species such as turkey and songbirds, and migrant species such as sandhill and whooping cranes).

- **Uplands**—Uplands are areas not classified as wetland or floodplain. They are often characterized by greater depth to groundwater and drier, more stable, mineral soil. Like wetlands, natural upland habitat communities exist in many forms (e.g., prairies, oak savanna, woodlands) and host critical life-cycle functions for many upland game and nongame wildlife species. For example, upland habitat provides critical breeding, nesting, resting, and feeding areas as well as acting as refuge from predators and weather extremes. However, unlike wetlands, the dry and stable soils make uplands more desirable/economically viable for urban development and, therefore, such areas are often more challenging to protect.

Both wetlands and uplands are critical to wildlife populations. The dynamic interactions and movement between these two habitat types is also crucial because many terrestrial organisms spend part of their time in wetlands and the rest of their time in upland areas. For example, toads live most of their lives in upland areas but depend on wetlands for breeding. Consequently, if connections between uplands and wetlands are compromised (e.g., if a large road is placed between two land types), it makes it dangerous, if not impossible, for amphibians to gain access to their breeding grounds, thereby reducing their ability to seasonally migrate or reproduce. In fact, habitat fragmentation (i.e., the splitting up of large connected habitat areas) has been cited as the primary global cause of wildlife population decreases.[167] Therefore, protecting and expanding uplands and wetlands, providing naturalized transition habitat, and maintaining or enhancing connectivity, help maintain or enhance wildlife populations. See "Riparian Buffer Protection and Prioritization Strategies" subsection of Section 2.3, "Nearshore and Stream Channel Inventory" and Appendix B for more details.

Figure 2.83
Examples of Wetland Types

Marsh

Scrub/Shrub

Forested

Source: (1) SEWRPC (2) University of New Hampshire Cooperative Extension (3) Prince William Conservation Alliance

[167] *L. Fahrig, "Effects of Habitat Fragmentation on Biodiversity," Annual Review of Ecology, Evolution, and Systematics 34: 487-515, 2003.*

MANAGEMENT RECOMMENDATIONS AND PLAN IMPLEMENTATION 3

Credit: Map data ©2021 Google

3.1 INTRODUCTION

Nagawicka Lake provides a long list of valuable services to lakeshore property owners, people visiting the Lake, and nearby residents. Furthermore, the Lake provides key ecological, water quality, and floodwater detention services to the larger Bark and Rock River watersheds due to its function as a headwater lake. Because of the Lake's great value to the nearby community and overall watershed, the Lake Welfare Committee (LWC) requested, and was subsequently awarded, a grant to study issues perceived to harm or threaten the Lake, and to suggest solutions to these problems. The resultant recommendations are listed in Table 3.1 and are based upon the interests and priorities of the stakeholder group,[168] analysis of available data, practicality, and the potential for successful implementation. Implementing these recommendations helps maintain and enhance the health of the Lake and improves its ability to provide short- and long-term benefit to the overall community.

The recommendations made in this chapter cover a wide range of programs and seek to address a broad array of factors and conditions that significantly influence the health, aesthetics, and recreational use of Nagawicka Lake. Since the plan addresses a wide scope of issues, it may not be feasible to implement every recommendation in the immediate future. To promote efficient plan implementation, the relative importance and significance of each recommendation is noted to help Lake managers prioritize plan elements. Nevertheless, all recommendations should eventually be addressed, subject to possible revision based on analysis of yet-to-be collected data (e.g., future aquatic plant surveys and water quality monitoring results), project logistics, and/or changing/unforeseen conditions.

Those responsible for Lake planning and management should actively conceptualize, seek, and promote projects and partnerships that enable the recommendations of the plan to be implemented. The measures presented in this chapter focus primarily on those that can be implemented through collaboration between local organizations, watershed property owners, and others who have a vested interest in the Lake's long-term health. Examples include the LWC, Lake residents, Waukesha County, the City of Delafield, and the Village of Nashotah. Collaborative partnerships formed among other stakeholders (e.g., other agencies within the

[168] *The LWC, Waukesha County, the City of Delafield, the Village of Nashotah, other nearby communities, the Wisconsin Department of Natural Resources, members of the general public, grass-roots organizations, and other agencies.*

Table 3.1
Nagawicka Lake Recommendation Summary: 2019

Recommendation Number	Recommendation	Priority
	Hydrology/Water Quantity	
1.1	Continue to monitor Nagawicka Lake's water surface elevation and Bark River flow	High
1.2	Develop Lake outlet rating curves	Medium
1.3	Manipulate Lake water elevation to avoid ice damage	Low
1.4	Mimic natural water level fluctuations to promote Lake health	Medium
1.5	Monitor groundwater elevation and use	Medium
1.6	Implement measures promoting stormwater storage and infiltration in existing urban areas	High
1.7	Reduce the impact of existing land use and future urban development on groundwater supplies	Low-High[a]
1.8	Promote good soil health	Low-High[a]
1.9	Purchase land or land conservation easements	Medium
1.10	Continue to protect sensitive areas	High
	Water Quality	
	Nagawicka Lake Monitoring	
2.1	Continue and enhance comprehensive water quality monitoring within Nagawicka Lake	High
	Bark River Monitoring	
2.2	Re-establish water quality monitoring at the US Geological Survey gaging	High
2.3	Install continuous turbidity monitoring program on the Bark River	Medium
	Phosphorus Management	
2.4	Reduce nonpoint source external phosphorus loads	High
2.5	Manage in-Lake phosphorus sources	High
2.6	Removing nutrients through aquatic plant harvesting	High
2.7	Promoting conditions conducive to muskgrass growth	High
2.8	Implementing hypolimnetic withdrawal and on-shore treatment	Low
	Pollutant and Sediment Sources and Loads	
	Watershed Level	
3.1	Protect and enhance buffers, wetlands, and floodplains	High
3.2	Protect buffer, wetland, and floodplain function	Medium
3.3	Protect remaining woodlands	Medium
3.4	Maintain stormwater detention basins	High
3.5	Promote urban nonpoint source abatement	High
3.6	Promote native plantings in and around existing and new stormwater detention basins	Medium
3.7	Combine riparian buffers with other structures and practices	High
3.8	Retrofitting existing and enhancing planned stormwater management infrastructure to benefit water quality	High
3.9	Collect leaves in urbanized areas	High
3.10	Stringently enforce construction site erosion control and stormwater management ordinances and creative employment of these practices	High
	Sub-Basin Level	
3.11	Prioritize pollutant load reduction practices by sub-basin pollutant loading	Low-High[a]
	Shoreline Maintenance Level	
3.12	Maintain shoreline protection and prevent streambank erosion	High
3.13	Reduce refracted wave energy	Medium
3.14	Encourage pollution source reduction efforts along shorelines through BMPs	High
3.15	Enforce ordinances	High
	Aquatic Plants	
	Aquatic Plant Management	
4.1	Aquatic plant harvesting to create access lanes	High
4.2	Continue aquatic plant harvesting to enhance recreational use	Low
4.3	Harvest nearshore nuisance plant growth	High
4.4	Deep-cut harvesting may occur in the Bark River delta in designated access	Medium
4.5	Apply early spring chemical treatment in access channels only in Sensitive Areas 1 and 2 if nuisance plant growth impedes Lake access	Low
4.6	Control growth of invasive plant species	High
4.7	Manually remove nuisance plant growth in nearshore areas	Medium
4.8	Harvesting must maintain, at minimum, one foot of living rooted aquatic plant material	High

Table continued on next page.

Table 3.1 (Continued)

Recommendation Number	Recommendation	Priority
	Aquatic Plants (continued)	
	Aquatic Plant Management (continued)	
4.9	Maintain and operate harvesting equipment in conformance with manufacturer's recommendations	High
4.10	Inspect all cut plants for live animals and immediately return live animals to water	High
4.11	Avoid harvesting in the early spring as much as possible	High
4.12	All harvester operators must successfully complete training course	High
4.13	Continue plant pickup program and encourage shoreline resident participation	High
4.14	All plant debris collected from harvesting activities must be collected and properly disposed of	High
	Native Plant Community and Invasive Species	
4.15	Protect native aquatic plants to the highest degree feasible	High
4.16	Actively manage invasive species to protect native plants and wildlife	High
4.17	Avoid disrupting bottom sediment or leaving large areas of bottom sediment devoid of vegetation	High
4.18	Implement chemical control methods in early spring	High
4.19	Prevent introduction of new invasive species	High
	Cyanobacteria and Floating Algae	
5.1	Reduce Lake water phosphorus concentrations	High
5.2	Continue to monitor algal abundance	Low-High[a]
5.3	Warn residents not to enter the water in the event of an algal bloom	High
5.4	Maintain or improve overall water quality	High
5.5	Maintain a healthy aquatic plant community to compete with algal growth	High
	Fish and Wildlife	
6.1	Understand fishery information, actively participate in the WDNR's planning process, and support management recommendations	High
6.2	Protect valuable in-Lake fish habitat and avoid disturbing vulnerable fish	High
6.3	Mitigate water quality stress on aquatic life and maximize areas habitable to desirable fish	High
6.4	Continue active management actions that safeguard and/or improve long-term water quality and may promote reintroduction of cisco	Low
6.5	Identify and remove instream barriers to passage of fish and other aquatic organisms	High
6.6	Improve in-Lake aquatic habitat by maintain, encouraging, or installing large woody structure and/or vegetation buffer along shorelines	Medium
6.7	Adopt best management practices to improve wildlife habitat	Medium-High
6.8	Promote aquatic plant management plan implementation to avoid inadvertent damage to native species	High
6.9	Preserve, enhance, and expand wetland and terrestrial wildlife habitat while enhancing ecological connectivity between natural areas	High
6.10	Monitor the diversity and abundance of fish and wildlife	High
	Recreational Use and Facilities	
7.1	Encourage safe boating practices and boating pressure on navigable portions of the Lake	Medium
7.2	Maintain and enhance swimming through engaging in "swimmer-conscious" management efforts	Medium
7.3	Maintain and enhance fishing by protecting and improving aquatic habitat and ensuring the fish community remains viable	Medium
7.4	Maintain public boat launch sites	High
7.5	Existing boating regulations should be reviewed for compatibility with current conditions and expectations and ordinances should be conscientiously enforced	Low-High[a]
7.6	Consider increasing launch fees during peak use periods	Medium
	Plan Implementation	
8.1	Maintain and enhance relationships with County, municipal zoning administrators, and law enforcement officers	High
8.2	Keep abreast of activities within the watershed that can affect the Lake	High
8.3	Educate watershed residents about relevant ordinances. Update ordinances as necessary to face evolving use problems and threats	High
8.4	Apply for grants to help implement plan-recommended programs	High
8.5	Broaden Lake Welfare Committee representation	High
8.6	Encourage Lake users and residents to actively participate in future management efforts	Medium

Table continued on next page.

Table 3.1 (Continued)

Recommendation Number	Recommendation	Priority
	Plan Implementation (continued)	
8.7	Encourage key players to attend meetings, conferences, and/or training programs to build lake management knowledge and enhance institutional capacity	Medium
8.8	Continue to reinforce stakeholder inclusivity and transparency with respect to all Lake management activities	High
8.9	Foster and monitor efforts to communicate concerns, goals, actions, and achievements to future Lake managers	High
8.10	Develop an action plan	High

[a] *The priority is based on the sub recommendations.*

Source: SEWRPC

Wisconsin Department of Natural Resources (WDNR), developers, non-governmental organizations (NGOs), wastewater treatment plants, and other watershed municipalities) help promote efficient, affordable, and sustainable actions to assure the long-term ecological health of Nagawicka Lake.

As a planning document, this chapter provides concept-level descriptions of activities that may be undertaken to help protect and enhance Nagawicka Lake and its watershed. It is important to note that plan recommendations provide stakeholders and implementing entities with guidance regarding the type and nature of projects to pursue to meet plan goals. These recommendations and project suggestions do not constitute detailed technical specifications. The full logistical and design details needed to implement most recommendations must be more fully developed in the future when individual recommendations are implemented. Grants are often available to develop concepts into actionable design drawings and plans.

In summary, this chapter provides those implementing the plan the ability to:

- Better understand plan element context and what actually needs to be done
- Judge the relative importance of plan elements
- Better comprehend plan intent
- Envision what various plan elements may look like

Such concepts can be invaluable for building coalitions and partnerships, writing competitive and meaningful grant requests, and initiating project design work.

3.2 HYDROLOGY/WATER QUANTITY

General Concepts

All waterbodies gain and lose water through various means. The source of all water supplied to the Region's waterbodies is precipitation. Although some waterbodies derive most water from runoff, tributary streams, and groundwater, these sources also ultimately depend upon precipitation. Waterbodies lose water in a number of ways including evaporation, plant transpiration, outflow, infiltration into beds and banks, and human withdrawal. When water inflow and outflow are not balanced, water elevations and streamflow fluctuate. If water supply is less than water demand, lake elevations can fall, and stream flows can be reduced or eliminated. During heavier than normal precipitation, lake and river levels may rise.

Humans modify water dynamics in a drainage basin. In particular, two human activities significantly affect the hydrology of a region:

- Installing impermeable surfaces and stormwater infrastructure hastens runoff, increases runoff volume, and discourages groundwater recharge. This in turn typically increases the volume of water reaching lakes and rivers during wet weather and decreases flow to waterbodies during dry weather.

- Pumping water from wells disrupts natural groundwater flow systems. If most of the pumped water is returned as groundwater after use, overall impact may be minimal. However, when water is either consumptively used (e.g., evaporated) or exported from the local groundwater flow system (carried by sanitary sewers that discharge effluent outside of the surface-watershed and groundwatershed), groundwater elevations may fall and discharge to and flow in surface-water features can be reduced or eliminated.

Such changes are generally detrimental to waterbody health. Therefore, management actions should attempt to reduce the impact of human-induced hydrologic change on waterbodies.

The Nagawicka Lake watershed is found at the periphery of the Milwaukee metropolitan area and is home to considerable numbers of people. As such, the watershed (especially the area downstream of the Village of Merton) has significant amounts of impervious land cover and large areas drained by stormwater collection and conveyance networks. Additionally, all water supply systems depend on groundwater, and large volumes of groundwater are exported from the watershed, reducing the volume of groundwater available to feed surface water features. Reduced recharge and high human water demand stresses the watershed's surface water and groundwater resources. This situation will likely intensify as the area continues to develop.

To maintain waterbody health and provide sustainable water supplies, action should be taken to counteract human activities that compromise sustainable, high quality, water supplies. In general management actions aim to slow runoff, maintain or increase groundwater recharge, and reduce the volume of water removed from flow systems feeding Nagawicka Lake and the Bark River. Examples of such approaches are described in the following paragraphs:

- **Detain stormwater.** Urban development often manipulates landscapes in ways that increase runoff volume and speed and decrease groundwater infiltration. Action can be taken to detain and more slowly release runoff, reduce peak runoff rates, and better approximate natural rainfall/runoff patterns. When water is detained, physical and biological processes are able to reduce pollutant and sediment loads. Many features on the natural landscape detain runoff (e.g., wetlands, floodplains, closed depressions). Efforts should focus on protecting and enhancing natural stormwater detention areas. If the capacity of natural features is insufficient to achieve the desired goals, stormwater can be detained in purpose-built artificial structures (e.g., stormwater detention basins, ditch checks, swales). Artificial detention features should be installed to service new developments or retrofitted to infrastructure in developed areas. With careful and holistic planning, it can sometimes be feasible to build detention features as part of new development that also serve existing development.

- **Infiltrate stormwater.** The most basic approach to maintain stormwater infiltration and groundwater recharge is to protect or enhance high and very high groundwater recharge potential areas. Map 3.1 compares areas of planned development with current groundwater recharge potential. Areas of planned development in areas of high and very high groundwater recharge potential should be required to design and install infrastructure maintaining or enhancing overall stormwater infiltration.

  To maintain or enhance infiltration, water should not be allowed to rapidly leave the land surface and soil health should be maintained or enhanced. Intensive development, drainage ditches, tiling and other soil drainage schemes, storm sewers, and soil compaction should be avoided, particularly in high and very high groundwater recharge potential areas and/or the impact of such modifications should be carefully mitigated by restoring or enhancing natural detention features with good connection to groundwater flow systems.[169] Positive action should be taken to promote soil health throughout the area contributing surface and/or groundwater to the Nagawicka Lake watershed. Healthy soils are more porous, are less prone to erosion, and, therefore, help improve baseflow and water quality.[170]

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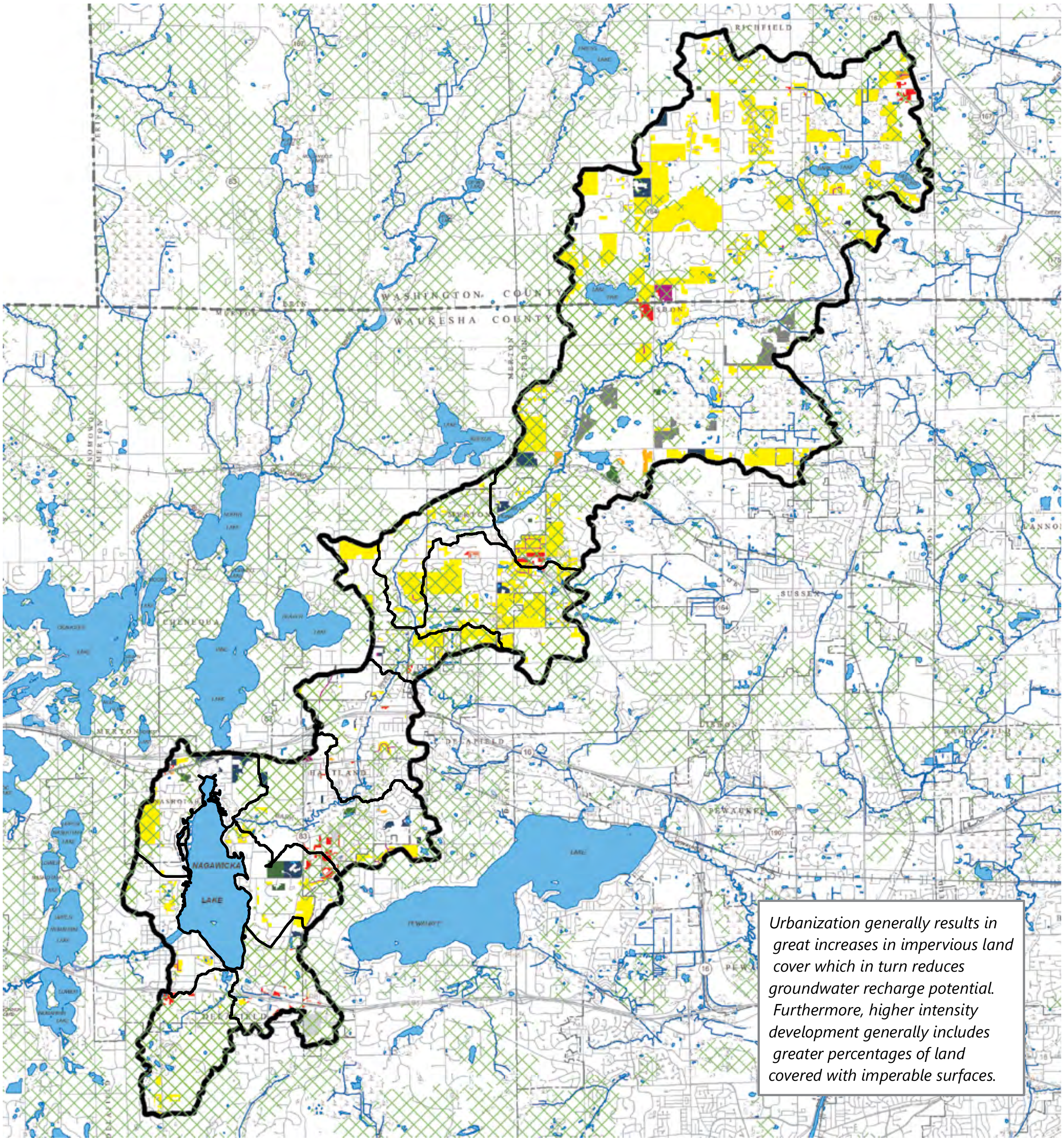
[169] *Detention features can be built that encourage infiltration of stored water and contribute to groundwater recharge. Such systems are one of only a few artificial methods that meaningfully reduce overall runoff volume. They are best situated in areas of high and very high groundwater recharge potential.*

[170] *More information regarding soil health can be obtained from many sources including the following website: www.nrcs.usda.gov/wps/portal/nrcs/main/national/soils/health.*

Map 3.1
Development Planned Between 2010 and 2050 and its Influence on Groundwater Recharge Potential



SINGLE-FAMILY RESIDENTIAL
MULTI-FAMILY RESIDENTIAL
COMMERCIAL
INDUSTRIAL
TRANSPORTATION, COMMUNICATIONS, AND UTILITIES
GOVERNMENT AND INSTITUTIONAL
RECREATION
EXTRACTIVE AND LANDFILL
SURFACE WATER
WETLAND
STREAM
WATERSHED BOUNDARY
SUBBASIN BOUNDARY
GROUNDWATERSHED BOUNDARY
HIGH AND VERY HIGH GROUNWATER RECHARGE AREAS

N
0 5,500 11,000 Feet

Source: SEWRPC

Given the significant quantity of groundwater exported from the watershed via sanitary sewers, maintaining, or more desirably increasing, surface water infiltration is very important. This action not only protects surface-water features and ecological health, but also helps safeguard the water supplies that humans in the region depend upon for drinking water and other uses.

- **Reduce Net Groundwater Demand.** Groundwater supplies all residential, commercial, and industrial water demands in the Nagawicka Lake watershed and surrounding areas. Additionally, much of the area is served by public sanitary sewers that export wastewater from the watershed. Therefore, much of the water drawn from local aquifers is exported from the watershed and no longer can supply baseflow to surface-water features. This is a vexing problem that has few solutions. However, action can be taken to reduce current and future net groundwater demand placed on local aquifers. Examples of such concepts are provided in the following text.

  - Promote enhanced stormwater runoff infiltration.

  - Institute a water conservation campaign focused on water demands now discharged to sanitary sewers.

  - Evaluate if clean-water discharges now directed to sanitary sewers or discharge points outside the watershed can be discharged to areas within the area contributing surface water and groundwater to Nagawicka Lake. An example would be redirecting non-contact cooling water drawn from onsite wells that has not been treated in any way to surface water.[171]

The strategies promoting the quantity, timing, and quality of water reaching surface water features are most efficiently applied to specific areas to have the desired effect. For example, groundwater recharge occurring outside of the groundwatershed of Nagawicka Lake does not support baseflow to the Lake. Nevertheless, groundwater recharge does support baseflow in neighboring lakes and streams. For example, water infiltrating from detention features in the Village of Hartland east of the Bark River supports groundwater systems discharging to Coco Creek and Pewaukee Lake. The complex interplay of surface water and groundwater flow systems creates a situation where different geographic areas have differing potential to protect and enhance water supply and quality. These areas are located in Map 3.2 and strategies that help protect/enhance the Lake's water supply are discussed below.

- The area within the Lake's watershed but outside of the recharge area of shallow groundwater flow systems feeding Nagawicka Lake and the Bark River are best suited to strategies that focus on detaining stormwater runoff and enhancing runoff water quality.

- Areas outside of the surface watershed but within the recharge area of the shallow groundwater flow systems feeding Nagawicka Lake and the Bark River are best suited to strategies that aim to increase stormwater infiltration and reduce net groundwater demand.

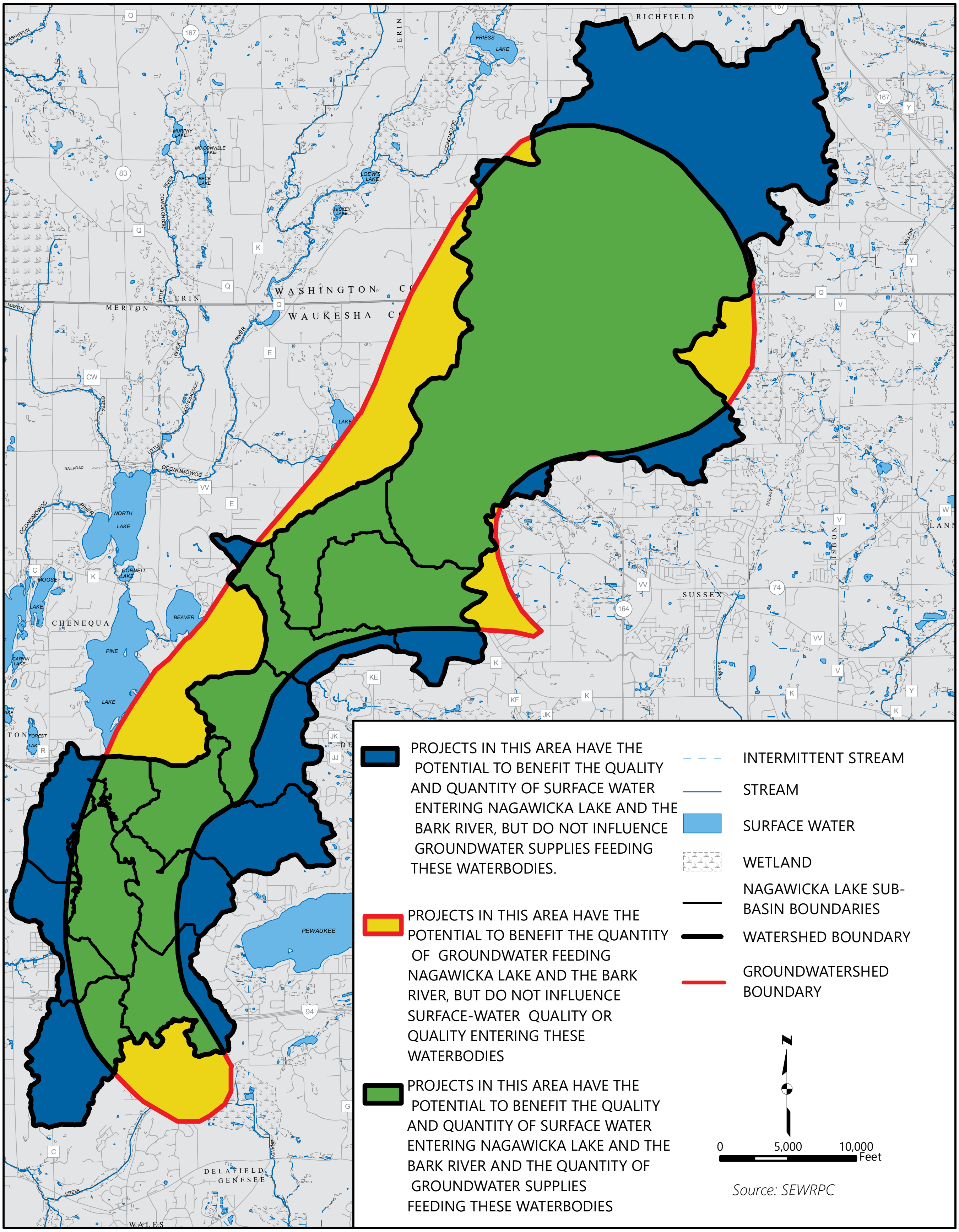
- Projects executed in the area that is within both the Lake's watershed and groundwatershed can benefit both the Lake's surface water and groundwater supply. Project in this area can used a combination of detention, infiltration, and net groundwater demand reduction.

Management Strategies

A management strategy addressing the Lake and River's water supply should capably identify opportunities, quantify change, and evolve. Management actions that help assure the Lake's long-term water supply include the following examples.

[171] *In some cases, municipal water supplies are treated with compounds (e.g., orthophosphate) that helps reduce corrosion in lead pipes. Additionally, disinfectants, fluoride, and other compounds are often added to municipal water supplies. These additives may be detrimental if discharged to surface water or groundwater.*

Map 3.2
How Projects May Benefit Local Water Resource Features



- **Recommendation 1.1: Continue to monitor Nagawicka Lake's water surface elevation and the flow of the Bark River**

  The elevation of the Lake is influenced by several factors including precipitation, evaporation, other weather conditions, the position of the gate at the outlet dam, and, during dry weather, the volume of groundwater discharging to the Lake and River. Variations in these factors are the primary reasons why Lake water levels fluctuate. Having on-the-ground local information relating these factors helps monitor human and environmental stressors on the Lake and River's water supply and could ultimately advance water resource engineering concept development and design. At the present time, the U. S. Geological Survey quantifies the volume of water entering Nagawicka Lake and the City of Delafield monitors the position of the outlet dam gates and the water surface elevation in the Lake. Continued monitoring of the Bark River's flow and Nagawicka Lake's elevation should be assigned a <u>high priority</u>.

- **Recommendation 1.2: Develop Lake outlet rating curves**

  To better understand the water budget of the Lake, the quantity of water leaving the Lake should also be monitored. This could be done by developing a series of rating curves relating Lake water elevation, gate position, and flow. Given the long-term value of this investment, developing Lake outlet rating curves should be given a <u>medium priority</u>.

- **Recommendation 1.3: Manipulate Lake water elevation to avoid ice damage and mimic natural level fluctuations**

  Aside from short-term fluctuations caused by extreme precipitation and other factors, Nagawicka Lake's water elevation has been held essentially static since 2010. The Lake's water surface elevation is permitted to range between 889.17 and 889.67 feet above National Geodetic Vertical Datum, 1929 adjustment (NGVD 29). Most lake managers hold water elevations at the lower range of their permitted range during winter to minimize shoreline and infrastructure damage caused by ice movement and pressure. The City of Delafield should consider drawing the Lake level down in fall as a pre-emptive measure to help avoid ice damage. Given that ice damage is not known to be a prominent issue on the Lake, this is assigned a <u>low priority</u>.

- **Recommendation 1.4: Mimic natural water level fluctuations to promote Lake health**

  Under natural conditions, lake elevations vary seasonally, commonly reaching their lowest levels in late summer. During protracted drought, water levels may be persistently low over periods of time totaling a year or more. By constructing dams with gates, humans attempt to vary lake discharge and maintain high stable water levels throughout the warm season to foster recreation. Some aquatic plants require low water levels during summer to survive. For example, bulrush may persist for years with static water levels, but will ultimately decline if the lake bottom is not periodically exposed. Bulrush seeds require such conditions to germinate. The LWC should consider periodic drawdowns to enhance high value native plant populations, help control nuisance plant populations (e.g., narrow leaf cattail), and allow consolidation and desiccation of nearshore unconsolidated silt and muck. Such action may require revision to the Lake elevation operating order. Given the concerns regarding unconsolidated sediment and cattails around portions of the Lake, this should be considered a <u>medium priority</u>.

- **Recommendation 1.5: Monitor groundwater elevation and use**

  The Village of Richfield, in the headwaters of the Bark River watershed, systematically monitors groundwater elevations and uses this information to make management decisions. Other sources of groundwater elevation information are undoubtedly available throughout the watershed (e.g., monitoring wells servicing remediation sites, landfills, quarries). The LWC could request copies of historical and ongoing groundwater elevation measurements to provide additional coverage. Finally, emerging, affordable technologies are available to collect groundwater information in water supply wells.[172] Implementing an expanded monitoring program should be considered a <u>medium priority</u>.

  The groundwater supplying the Lake and River are also heavily used for potable and industrial water supply, a situation that likely measurably diminishes the amount of groundwater entering natural

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[172] *An example of groundwater elevation monitoring equipment can be found at the following website: www.wellntel.com. This reference does not constitute an endorsement of the products offered by this firm, but rather is provided for general illustration. The LWC could consider encouraging participation by offering incentives to those contributing data.*

waterbodies. Municipal and private high-capacity wells must report the volume of water pumped each year. The LWC should request copies of production records in the watershed and track historical, current, and future human groundwater demands. This will help chart the degree of stress placed on the water supplies feeding the Lake and River and should be considered a medium priority.

- **Recommendation 1.6: Implement measures promoting stormwater storage and infiltration in existing urban areas**

  Implementing this recommendation could involve the following elements:

  - **Enhance the ability of rainfall and snowmelt to be detained, filtered, and/or infiltrated into soils.** This could be most easily achieved by installing modern stormwater best management practices (BMPs) associated with low-impact development, including rain gardens and other stormwater infrastructure specifically designed and carefully located to slow runoff, improve water quality, and promote infiltration.[173] Examples of simple infiltration measures include voluntarily directing stormwater to areas of permeable soil and favorable topography or minimizing impermeable surfaces. An example of redirecting stormwater is disconnecting roof downspouts from storm sewers. Such initiatives can be promoted by active educational outreach, providing instructions and supplies to property owners, and/or through subsidies. Some practices and projects, especially on public property, may qualify for partial funding through the WDNR Healthy Lakes & Rivers program. Given the relatively low cost and relative ease of implementation, this recommendation should be given a high priority throughout the watershed, with particular emphasis given to the portion of the watershed that is also within the groundwatershed.

  - **Integrate advanced stormwater management practices into local permitting processes.** A step toward a more comprehensive approach that benefits human habitation and waterbody health would be an ordinance requiring onsite stormwater management practices such as detention, permeable conveyance, limits to impervious surface, porous pavement, or other measures as a condition of issuance of a building permit affecting the overall impermeable surface area of a parcel. Such ordinances should be actively enforced when they exist or should be incorporated into existing ordinances. This should be considered a high priority.

  - **Retrofitting existing stormwater management systems with features that enhance water quality and/or modulate runoff rates.** Public works projects can be completed that modernize and improve stormwater management within areas of existing urban development. Retrofitting elements such as stormwater retention/infiltration basins, bioswales, permeable conveyance, and other infrastructure elements can help reduce the impact of existing development on water quality and quantity. In certain instances, stormwater infrastructure built for new development can be located and sized to manage stormwater runoff from existing development. Such projects are commonly difficult to execute and costly but given the amount of sediment pollutants identified to emanate from areas of existing development, such approaches could significantly reduce overall pollutant loads to the Lake and River. Therefore, this recommendation should be assigned a range of priorities in relationship to the associated benefits. With this in mind, the Commission recommends the following priorities:

    - High priority in sub-basins 10 and 11 (Lake-direct drainage basins located to the west of the Lake)

    - Medium priority in sub-basins 7 and 8 (Lake-direct drainage basins located to the east of the Lake) and in sub-basins 5 and 6 (the Village of Hartland)

    - Low priority in all remaining sub-basins

[173] *Rain gardens are depressions that retain water, are vegetated with native plants, and help water infiltrate into the ground rather than enter the Lake through surface runoff. Rain gardens can help reduce erosion and the volume of unfiltered pollution entering the Lake and can also help augment baseflow to the Lake.*

- **Recommendation 1.7: Reduce the impact of existing land use and future urban development on groundwater supply**

  This recommendation can be implemented by:

  - **Promoting water conservation and avoid discharge of potable water to sanitary sewers**. Instead, discharge clean water to adsorptive soil areas, storm sewers, or surface water features. This recommendation should receive a high priority.

  - **Carefully controlling new development in the watershed's best groundwater recharge potential areas.** This helps assure local and sometimes regional groundwater flow systems are protected. Control can include excluding certain types of development, maintaining recharge potential through thoughtful design, and minimizing impervious surface area. Consider purchasing or obtaining protective or conservation easements on open lands with high and very high groundwater recharge potential. Promote policies that protect or enhance infiltration on public lands. The recommended priorities for preserving recharge areas are:
    - High priority should be given to areas identified as having high and very high groundwater recharge potential within the groundwatershed feeding Nagawicka Lake and the Bark River.
    - Medium priority should be given to moderate groundwater recharge potential areas within the groundwatershed feeding the Lake and River.
    - Low priority should be assigned to low groundwater recharge potential areas within the groundwatershed feeding the Lake and River and all areas outside the groundwatershed feeding Nagawicka Lake.

  - **Requiring compliance with the infiltration and groundwater management regulations and recommendations** found in municipal ordinances (high priority).

  - **Encouraging developers to actively incorporate infiltration in new stormwater infrastructure** (high priority). Such infrastructure is best located on area of high and very high recharge potential. Infiltrated water must be good quality.

  - **Encouraging local government to consider balancing groundwater recharge and groundwater demand as an integral part of new development and infrastructure replacement proposals.** Some Southeastern Wisconsin communities have promulgated ordinances that require integrated analysis of groundwater and surface water impact in the process through which developers obtain permission to build new buildings and subdivisions (high priority).[174]

  - **Critically examining proposals that export water from the groundwatershed** (high priority).

- **Recommendation 1.8: Promote good soil health**

  This is most widely applicable to agricultural lands within the watershed, but the principles can also be applied to other lands such as parks and lawns (high priority). Consider offering advice and possibly financial incentives to support adoption of agricultural BMPs like cover crops and no-till agriculture. While all agricultural land can benefit from these practices, applying these practices to lands closest to waterbodies tributary to Nagawicka Lake will likely benefit the Lake's water quality the most. Appendix E prioritized agricultural tax parcels for implementation of agricultural BMPs while Figure 3.1 shows the total acreage for each priority class by sub-basin. Section 3.4, "Pollutant Sources and Loads" provides more information on soil health practices and organizations promoting soil health initiatives in Southeastern Wisconsin.

- **Recommendation 1.9: Purchase land or land conservation easements**

  Target agricultural and other open lands within Nagawicka Lake's groundwatershed that are identified as having very high or high groundwater recharge potential (medium priority).

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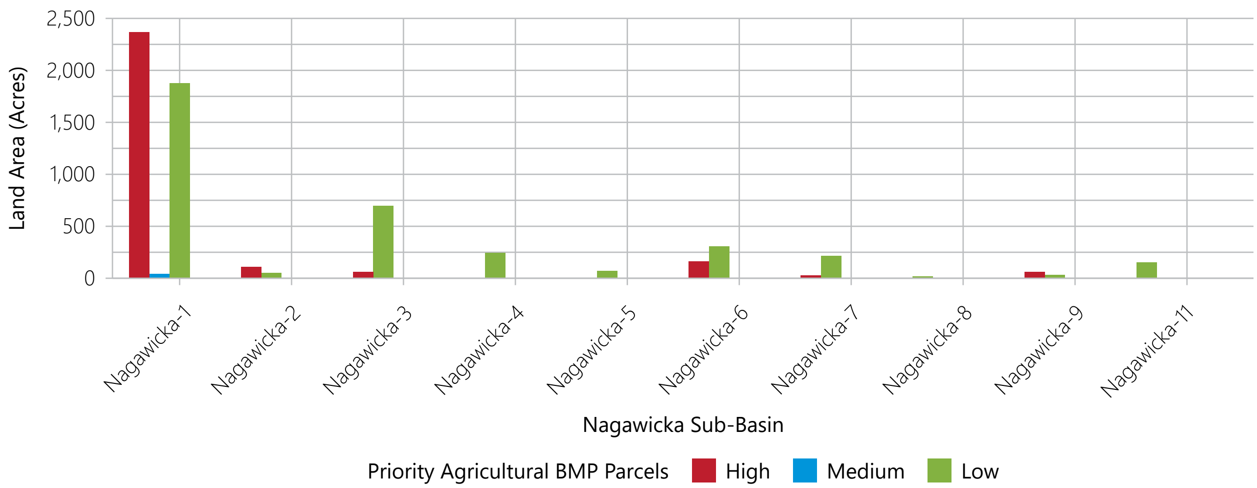
[174] *The Village of Richfield, located within the Bark River watershed in Washington County, is such an example. More information may be found at the Village's website: www.richfieldwi.gov/300/Groundwater-Protection.*

Figure 3.1
Total Acres of Agricultural Best Management Practices (BMP) Parcels for Nagawicka Sub-Basins



Source: SEWRPC

➤ **Recommendation 1.10: Continue to protect sensitive areas**
These sensitive areas provide numerous water quality, water quantity, and habitat benefits. Enforce town, village, and city zoning ordinances as discussed in Section 3.3, "Water Quality." This recommendation should be given a high priority.

As with the other recommendations made in this chapter, any unanticipated, long-term, or large future changes in the Bark River's flow or the water elevation of Nagawicka Lake would spur the need for re-evaluation of these recommendations. Consequently, flow and water elevation data should be periodically examined, and the suitability of water quantity recommendations should be re-evaluated. This process should be assigned a high priority.

3.3 WATER QUALITY

The fact that Lake residents are concerned with various water-quality-related issues (e.g., sources of pollution in the watershed, the volume of aquatic plant growth, algal growth) suggests that Lake water quality management is warranted. As explained in Chapter 2, management efforts to improve Nagawicka Lake's water quality should focus on strategies that enhance water quality monitoring and manage phosphorus.

Water Quality Monitoring

➤ **Recommendation 2.1: Enhance comprehensive water quality monitoring within Nagawicka Lake**
Water quality monitoring is an important tool that helps quantify the Lake's current condition, helps lake managers decipher longer term change, and allows the factors responsible for change to be identified. Monitoring is integral to management efforts aiming to maintain and improve Lake health. Therefore, monitoring water quality should be a high priority.

Water quality data has been collected for many years at the deepest location in the Lake. To allow historical data to be contrasted to current conditions, and, thereby, allow trends to be identified, samples should continue to be collected at the "deep hole" site. At a minimum, water quality samples should be collected and submitted to a laboratory in early spring shortly after ice out (e.g., early April) and at least once during mid-summer when the Lake is strongly stratified (e.g., late July). Field measurements (e.g., water clarity, temperature, and dissolved oxygen) should be collected much more frequently (e.g., at least twice per month during open water periods). At a minimum, water quality samples should be analyzed for the following parameters:

- Field measurements
    - Water clarity (i.e., Secchi depth)
    - Temperature (profiled over the entire water depth range at the deepest portion of the Lake with more frequent readings near the thermocline)
    - Dissolved oxygen (profiled over the entire water depth range at the deepest portion of the Lake with more frequent readings near the thermocline)
    - Specific conductance (near-surface sample, profiles with depth if equipment is available)
    - pH (near-surface sample, profiles with depth if equipment is available)
- Laboratory samples
    - Total phosphorus (near-surface sample with supplemental samples collected during summer near the deepest portions of the Lake)
    - Total nitrogen (near-surface sample)
    - Chlorophyll-*a* (near-surface sample)
    - Chloride (near-surface sample)
    - Alkalinity (near-surface sample)

Laboratory tests quantify the amount of a substance within a sample under a specific condition at a particular moment in time and provide valuable benchmarks and trend-defining values. Phosphorus, nitrogen, and chlorophyll-*a* analyses are the basic suite of parameters used to determine and track overall lake health. These parameters are tested in most lakes and are useful to contrast the Lake's health to other waterbodies of interest. Chloride is a particular concern in the Region and is the focus of an ongoing Commission study.[175] Excessive chloride concentrations are indicative of heavy human influence and are commonly associated with environments more favorable to undesirable aquatic invasive species. Alkalinity is of particular importance to the process that drives in-lake phosphorus sequestration. High alkalinity levels must be maintained to preserve the Lake's natural ability to sequester phosphorus.

Field measurements are often reasonable surrogates for common laboratory tests. For example, water clarity decreases when total suspended solids and/or chlorophyll-*a* concentrations are high, samples with high concentrations of total suspended solids commonly contain more phosphorus, and water with higher specific conductance commonly contains more salt and, therefore, more chloride. Periodically sampling water and running a targeted array of laboratory and field tests not only provides data for individual points in time but can also allow laboratory results to be correlated with field test results. Once a relationship is established between laboratory and field values, field data can be used as an inexpensive means to estimate the concentrations of key water quality indicators normally quantified using laboratory data.

The Clean Lakes Monitoring Network (CLMN) provides training and guidance regarding monitoring lake health.[176] Volunteers commonly monitor water clarity, temperature, and dissolved oxygen throughout the open water season (preferably every 10 to 14 days) and basic water chemistry (i.e., phosphorus and chlorophyll-*a* concentrations) four times per year (two weeks after ice-off and during the last two weeks of June, July, and August).

[175] *SEWRPC Planning Report No. 57,* A Chloride Impact Study for the Southeastern Wisconsin Region*, in progress.*

[176] *More information regarding the CLMN may be found at the following website: uwsp.edu/cnr-ap/UWEXLakes/Pages/programs/clmn/default.aspx.*

Supplemental temperature/oxygen profiles collected at other times of the year (e.g., other summer dates, nighttime summer, fall, winter) can be helpful. For example, temperature/oxygen profiles collected during midsummer nights, just before sunrise, help evaluate diurnal oxygen saturation swings. Additionally, oxygen/temperature profiles should occasionally be measured in other portions of the Lake during summer to help evaluate the homogeneity of temperature and oxygen concentrations throughout the Lake. The locations of such supplemental sampling points need to be carefully selected and documented.

Conductivity profiles collected during late fall, winter, and early spring would help quantify the impact of salt released into the Lake. In addition, the Lake's chloride concentration should also be monitored at least once per year when the Lake is fully mixed. Monitoring chloride concentrations allows the rate of concentration increase and variability over time to be quantified. This will help discern the overall impact of cultural influence on the Lake and to evaluate if chloride concentrations are approaching levels that could foster negative changes in the Lake's ecosystem.

Regular water quality monitoring helps Lake managers identify variations in the Lake's water quality and improves the ability to understand problems and propose solutions. Given the changing landscape in which Nagawicka Lake is situated, water quality and the conditions influencing water quality can change. Regular review and revision of water quality monitoring recommendations should be considered a high priority.

- **Recommendation 2.2: Re-establish water quality monitoring at the US Geological Survey gaging station on the Bark River just upstream of Nagawicka Lake**

  The US Geological Survey gaging station now quantifies the rate and volume of water entering the Lake from the Bark River. This provides an opportunity to quantify the mass of constituents reaching the Lake from the River. Unfortunately, collecting continuous parameter-specific concentrations (e.g., phosphorus, chloride), while desirable, is likely not practical for the LWC because of excessive cost and complexity. However, relatively inexpensive and easy-to-operate monitoring can be used to collect information that help managers judge the River's loading to the Lake. For example, Commission staff installed specific conductance monitoring equipment at the gaging station under the Regional chloride study. The Commission is collecting samples at this location for determination of chloride concentrations, allowing development of a mathematical relationship between conductivity values and chloride concentrations. When such a relationship is successfully established, the conductivity values can be used to estimate the mass of chloride delivered to the Lake from the Bark River. Incorporating the Commission's future conductivity values and chloride estimates into future management decisions should be a high priority.

- **Recommendation 2.3: Install continuous turbidity monitoring program on the Bark River**

  The LWC should consider installing a continuous reading turbidity monitoring device to estimate the amount of suspended sediment contributed to the Lake by the Bark River. Turbidity values may be able to be correlated with total suspended solids and phosphorus loads if appropriate calibration sampling is completed. Oxygen concentrations and temperature should also be periodically measured at set stations along the Bark River, especially during the spring and summer, to evaluate habitat condition. Turbidity monitoring at the gaging station and measuring temperature and oxygen concentrations along the river course should be considered by the LWC and assigned a medium priority.

Phosphorus Management

- **Recommendation 2.4: Reduce nonpoint source external phosphorus loads**

  Nagawicka Lake has a large watershed, and, therefore, it can receive significant sediment and pollutant loads from the Bark River and tributaries that discharge directly to the Lake. The urbanized Lake-direct tributaries contribute far more phosphorus per acre of land than the remainder of the watershed. However, the largest external mass load of phosphorus enters the Lake via the Bark River. Nonpoint phosphorus loads should be reduced to the maximum extent practicable, and reduction strategies should be assigned high priority. This issue is discussed in more detail, and strategies to reduce loads are presented in Section 3.4, "Pollutant Sources and Loads."

- **Recommendation 2.5: Manage in-Lake phosphorus sources**

  Available evidence suggests that phosphorus internal loading and recycling contributes about the same amount of phosphorus to the Lake's water column as do external nonpoint sources. Therefore, actions taken to reduce internal phosphorus cycling can also have a profound effect on water quality and aquatic plant/algae abundance. Overall water quality and habitat value could likely be enhanced by decreasing the Lake's limiting plant nutrient (phosphorus). This in turn would help the Lake be less eutrophic, reduce the incidence and severity of algal blooms, lessen stress on the Lake's fish and aquatic life communities, help assure that natural plant-induced phosphorus sequestration processes continue, and sustain a high-quality ecosystem with more long-term resilience. Reducing excess phosphorus is key to this dynamic; therefore, managing in-Lake phosphorus should be assigned a high priority. Additional data may need to be collected to evaluate internal loading dynamics and monitor effectiveness more fully. For example, additional water chemistry profiles and sediment samples from the deep portions of the Lake may need to be collected to better quantify internal loading rates.

  While a large variety of techniques can be used to reduce internal recycling of phosphorus, two or three approaches appear to be most promising for Nagawicka Lake. Chemical inactivation using alum is not likely to provide lasting control, since external phosphorus loads are very significant. It should be remembered that a combination of approaches, as opposed to choosing a single strategy, will typically provide the best results.

- **Recommendation 2.6: Removing nutrients through aquatic plant harvesting**

  Removing nutrients through aquatic plant harvesting should be considered a high priority in Nagawicka Lake. Plant harvesting has the potential to remove significant amounts of phosphorus from the Lake, offsetting phosphorus loading from external and internal sources, and potentially reducing the availability of legacy phosphorus. Chemical herbicides should be avoided since they allow nutrients to remain in the Lake in the form of dead plant material. A new small aquatic plant harvester specially designed for tight quarters and shallow waters may be a good alternative in areas inaccessible to current harvesting equipment. See Section 3.5, "Aquatic Plant Management," for additional information.

- **Recommendation 2.7: Promoting conditions conducive to muskgrass growth**

  Muskgrass (*Chara* spp.) growth sequesters phosphorus and is a significant factor in some lakes' ability to absorb high phosphorus loads yet maintain good water quality. Muskgrass commonly favors areas of groundwater discharge, therefore, the volume of groundwater discharge to the Lake must be maintained. Clearer water can contribute to increased muskgrass growth, forming a positive self-reinforcing feedback loop. Muskgrass should not be a target of aquatic plant harvesting or herbicide treatment. This recommendation should be assigned a high priority.

- **Recommendation 2.8: Implementing hypolimnetic withdrawal and on-shore treatment**

  Implementing hypolimnetic withdrawal and on-shore treatment involves drawing water from deep anoxic areas of a lake, piping it to a convenient location on the shoreline, and manipulating water chemistry using natural processes and/or induced physical and/or chemical means to cause phosphorus to come out of solution. Given the large volume and extent of deep-water areas in Nagawicka Lake, and the continuing loading from the Lake's large watershed, hypolimnetic withdrawal and treatment is presently impractical, and is assigned a low priority, and is therefore not described in detail.

As with the other recommendations made in this chapter, any unanticipated, long-term, or large future changes in the tributaries' flow or the water elevation of Nagawicka Lake would spur the need for re-evaluation of these recommendations. Consequently, flow and water elevation data should be periodically examined, and the suitability of water quantity recommendations should be re-evaluated. This process should be assigned a high priority. Implementing these recommendations will significantly contribute to tracking and improving water quality in Nagawicka Lake.

3.4 POLLUTANT SOURCES AND LOADS

Nagawicka Lake is a fairly typical hard-water, alkaline lake with relatively good water quality and with no significant point source pollution. Anticipated land use changes between current and planned land use suggest that 4,537 acres of rural, mainly agricultural, lands in the Lake's watershed will be converted to urban (mostly residential) use. This change will likely influence the Lake's water quality in a number of ways, including an overall decrease in sediment loading to the Lake and an increase in metal pollutant loading. Available data shows that a great deal of phosphorus is stored in the Lake's bottom sediment, some of which could re-enter Lake water under anoxic conditions. Although the Bark River is the single largest contributor of sediment and phosphorus to the Lake, urbanized Lake-direct drainage areas to the west of the Lake contribute far more sediment and phosphorus to the Lake per individual acre of drainage basin. This points to the need to the practicality of investing money where it has the capacity to be the most effective. Therefore, certain areas should be prioritized for active management action.

Rural Upland Sediment and Nutrient Sources

General Concepts and Importance

As explained in Chapter 2, riparian corridors have an important role in controlling the amount of sediment reaching lakes and streams. Well-vegetated buffers, floodplains, and wetlands can help capture much of the sediment, nutrients, and other pollutants draining from and sourced within upland areas. While it is vitally important to maintain, and better yet enhance, the ability of riparian corridors to reduce sediment, nutrient, and pollutant loads to streams, it is arguably even more important to reduce the volume of these pollutants released from upland areas. Post-European settlement land uses greatly increased the amount of sediment and nutrients released from upland areas throughout Southeastern Wisconsin. This is largely related to removing native forest and grassland cover over broad areas and replacing perennial land cover with annual crops, livestock pasture, and other intensive agricultural land uses. Agricultural land uses are the largest contributors of sediment and phosphorus to most Southeastern Wisconsin waterbodies.

While eroding streambanks and stream channels may be visually striking examples of how human land use accelerates soil loss, the actual volume of sediment delivered to waterbodies by such features is generally dwarfed by the continual, slow, insidious erosion of a few millimeters of soil per year over broad expanses of upland landscape. To illustrate this point, the USDA Natural Resource Conservation Service (NRCS) estimates that average annual cropland soil loss in Wisconsin is 3.1 tons per acre per year, which translates to an average soil loss of roughly 1/50th of an inch per year. While this value sounds small, this value is the same as seven to nine tri-axle dump truck loads of soil leaving a 40-acre field each year. This sediment, composed primarily of precious and nutrient rich topsoil, is deposited in downslope locations such as riparian areas, rivers, and lakes. This dramatically points to the great value of any initiative that aims to reduce upland soil erosion.

Mitigation Strategies

The importance of reducing soil erosion in upland areas has been widely embraced for nearly a century. In recognition of the harm being done to the nation's landscape and the people who depended upon it, the United States Congress appropriated five million dollars in the heart of the Great Depression (i.e., 1933) to establish the Soil Erosion Service. Wisconsin was on the vanguard of this initiative, with the Coon Creek project area in Western Wisconsin being a pioneering incubator of concepts and practices. While practices have been refined over time, on account of the great importance of this vital topic, the interest in this initiative has not waned. Hundreds of practices are now approved to help combat soil erosion, many of them supported through cost sharing grants. While it is beyond the scope of this project to explain the details of every potential practice and source of funding, the NRCS provides information on available funding programs through its website.[177]

In the past decade, several formerly obscure yet novel soil erosion reduction initiatives have been gaining prominence. These initiatives can be categorized under two broad categories: soil health and producer-led conservation initiatives. Each initiative has broad application in the Nagawicka Lake watershed and is briefly summarized in the following text.

<u>Soil Health</u>

Soil health initiatives focus on restoring a soil's natural ability to absorb and store precipitation, process and store nutrients, maintain healthy soil structure, support access of heavy equipment, and lessen dependence on tilling and introduced nutrients and pesticides. Soil health initiatives require producers to learn new processes and often require several years to realize the tangible benefits improved soil health can offer

[177] *To see these programs, visit www.nrcs.usda.gov/wps/portal/nrcs/main/wi/programs/financial.*

producers. Practitioners in Southeastern Wisconsin report decreased production cost, stable or increased crop yield, and therefore, increased overall farm profit per acre. From an environmental perspective, soil health initiatives decrease runoff, stabilize soil structure reducing the susceptibility of soils to erosion, and lessen or eliminate the need for tilling and artificial nutrient/pesticide applications. These changes decrease the amount of sediment, nutrients, and pesticides carried to waterbodies and sustains or improves groundwater recharge. On an overall basis, successfully employed soil health initiatives are one of the few truly symbiotic conservation initiatives—producers reap economic benefit while at the same time fostering environmental health.

Soil health initiatives include a broad spectrum of activities such as interseeding, cover crop establishment, modified tillage, nutrient, and pest management practices. Many events are sponsored on local, regional, and national levels to educate producers on the principles and practices of soil health. For example, the NRCS hosts a webpage devoted to distributing soil health information.[178] Local NRCS agents are also well versed in this initiative and can be an excellent resource to consult. Another national source of soil health information is the Soil Health Academy, an organization that sponsors local and regional events across the nation.[179]

County land managers are also excellent potential sources of information. Several Southeastern Wisconsin counties are actively engaged in soil health initiatives. Ozaukee, Racine, and Washington Counties have been particularly active in supporting soil health initiatives. Links to these counties' land management departments and/or soil health initiative websites are provided below.

- Ozaukee County:
  www.co.ozaukee.wi.us/295/Land-Water-Management

- Racine County:
  www.racinecounty.com/departments/public-works-and-development-services/land-conservation

- Washington County:
  www.co.washington.wi.us/departments/planning_and_parks/land_resources

Beyond government agencies, nonprofit organizations and private practitioners/consultants are available to assist interested producers to evaluate soil health initiatives, plan execution, implement practices, and monitor results. For example, a producer led watershed group in Waukesha County has partnered with the following organizations:

- Oconomowoc Watershed Protection Program:
  oconomowocwatershed.com

- Tall Pines Conservancy:
  tallpinesconservancy.org

<u>Producer-Led Watershed Groups</u>

Over the years, most agricultural conservation initiative grant funding was distributed through local, state, or federal government agencies. Beginning in 2016, the Wisconsin Department of Agriculture, Trade, and Consumer Protection (DATCP) initiated a grant program directed to groups of at least five farmers collaborating with conservation agencies, institutions, or nonprofit organizations that collectively endeavor to reduce farm field runoff and increase voluntary participation in conservation initiatives.[180] Throughout Southeastern Wisconsin, producer-led watershed groups have been taking leading positions in the soil health initiative. Links to these groups' websites are listed below.

- Clean Farm Families, Milwaukee River Watershed, Ozaukee County:
  www.cleanfarmfamilies.com

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[178] *For more information, see www.nrcs.usda.gov/wps/portal/nrcs/main/wi/soils/health.*

[179] *For more information, see soilhealthacademy.org.*

[180] *datcp.wi.gov/Pages/Programs_Services/ProducerLedProjects.aspx.*

- Cedar Creek Farmers, Cedar Creek Watershed, Washington County: cedarcreekfarmers.wixsite.com/website

- Watershed Protection Committee of Racine County, Fox and Root River Watersheds, Racine County: www.wpcracinecounty.org

- Farmers for Lake Country, Oconomowoc River Watershed, Waukesha County: farmersforlakecountry.org

These producer-led initiatives have seen remarkable success and are an excellent mechanism to introduce new ideas at the grass-roots level.

Linking the Rock River TMDL to Implementing Water Quality Improvements

The U.S. Environmental Protection Agency (USEPA) and the WDNR identified the Bark River watershed as a significant contributor of phosphorus and sediment to the Rock River. Certain Bark River reaches are listed as impaired for low dissolved oxygen concentrations. The USEPA and the WDNR established a total maximum daily load (TMDL) in 2011 to improve conditions producing low dissolved oxygen and degraded habitat in the Rock River basin.[181] A TMDL allocates the allowable load between point sources such as municipal wastewater treatment plants, industrial dischargers, concentrated animal feeding operations, and municipal separate storm sewer systems (MS4s); nonpoint sources such as agricultural sources, urban sources not covered under a discharge permit, and natural background loads; and a margin of safety. The Rock River TMDL addresses impairments such as oxygen depletion, nuisance algae growth, reduced populations of submerged aquatic vegetation, water clarity problems, and degraded habitat resulting from high concentrations of total phosphorus and sediment.

This TMDL established annual baseline total phosphorus and total suspended sediment loads and sets reduction goals for nonpoint sources, wastewater treatment facilities, and MS4s for both TP and sediment. The TMDL covers 84 sub-basins of the Rock River Basin, including sub-basin 55 where the Nagawicka Lake watershed is located (Map 3.3). Annual total phosphorus load reduction goals for the Nagawicka Lake watershed are 79 percent (1,786 lbs.) for wastewater treatment facilities, 68 percent (894 lbs.) for MS4s, and 54 percent (518 lbs.) for nonpoint sources. The TMDL also requires baseline sediment loads reductions of 43 percent (139 tons) from MS4s, 39 percent (80 tons) from nonpoint sources, and 28 percent (11 tons) for wastewater treatment facilities.[182] Of these nonpoint source loads, non-permitted urban sources contributed 14 percent (73 lbs.) of the total phosphorus and 11 percent (9 tons) of the sediment.[183] These load reduction goals should be considered the minimum standard that communities and permitted entities strive to attain. Additionally, while these load reductions targets are important for establishing water quality goals, it is equally important to recognize that continued phosphorus and sediment monitoring are the ultimate determinant of water quality within the watershed.

Choosing a management strategy is critical to meet these water quality goals. As a local example within the Rock River basin, the City of Oconomowoc has identified adaptive management as the preferred compliance alternative to meet its Wisconsin Pollutant Discharge Elimination System (WPDES) permit requirements for its wastewater treatment facility and MS4s under Chapters NR 217, "Effluent Standards and Limitations for Phosphorus," and NR 216, "Storm Water Discharge Permits," respectively, of the *Wisconsin Administrative Code*. The City submitted a preliminary Watershed Adaptive Management Request Form 3200-139 on February 23, 2015, and the WDNR approved their Adaptive Management Plan (AMP) on September 15, 2015. The AMP spans three WPDES permit terms or 15 years, with the understanding that progress can be demonstrated by the beginning of the third term. In order to achieve these water quality goals, the City has developed the Oconomowoc Watershed Protection Program to build capacity and develop collaborative projects within the watershed.

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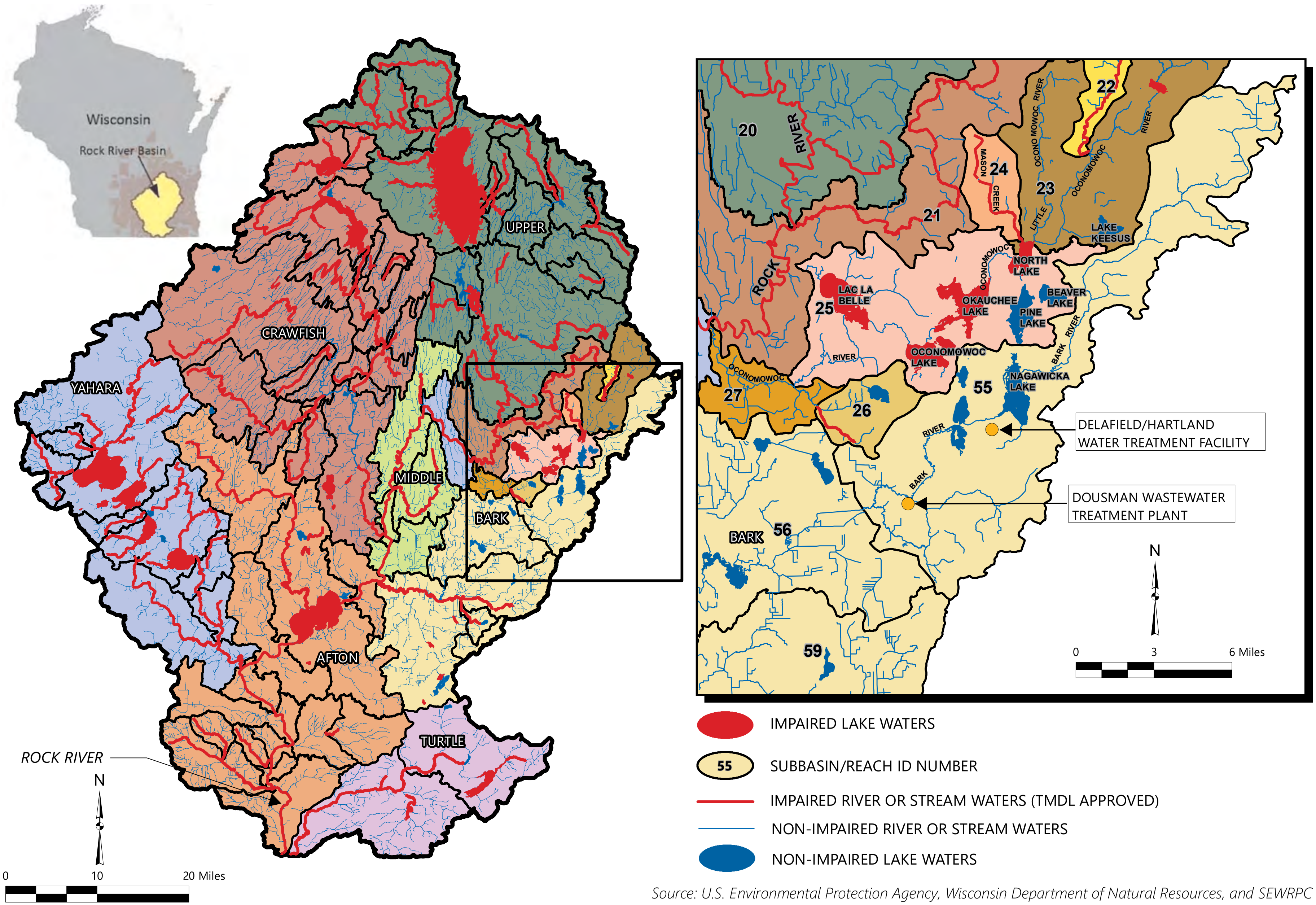
[181] *USEPA and WDNR,* Total Maximum Daily Loads for Total Phosphorus and Total Suspended Solids in the Rock River Basin Columbia, Dane, Dodge, Fond du Lac, Green, Green Lake, Jefferson, Rock, Walworth, Washington, and Waukesha Counties*, Wisconsin, prepared by the CADMUS Group, July 2011.*

[182] *Ibid.*

[183] *Ibid.*

Map 3.3
Sub-Basins and Impaired Reaches of Wisconsin's Rock River Watershed: 2018



Source: U.S. Environmental Protection Agency, Wisconsin Department of Natural Resources, and SEWRPC

Given its similar nature and goals, local partners within the Bark River watershed should consider the Oconomowoc River watershed adaptive management program as a framework to implement the management actions recommended in this plan. For example, a similar adaptive management approach could be pursued by the DelaHart wastewater treatment facility to meet its WPDES permit requirements—such an approach would require collaboration amongst individuals and municipalities in the Nagawicka Lake watershed. If successfully implemented, such an approach could save the DelaHart facility money and could improve water quality throughout the Nagawicka Lake watershed. Collaborative projects could be implemented throughout the Nagawicka Lake watershed, as load reduction anywhere within Lake watershed will count towards meeting the goals for the Bark River watershed as a whole. Recommendations for best management practices that could be implemented as adaptive management projects are summarized in the following text.

Watershed Level Recommendations

Since certain features naturally filter or remove pollutants before runoff reaches waterbodies, it is important to evaluate where such features exist within the Lake's watershed and to what degree they may be able to mitigate pollutant loading of metals, nutrients, or sediment. It should be noted that these features may overlap and may provide multiple benefits.

➤ **Recommendation 3.1: Protect and enhance buffers, wetlands, and floodplains**

Protecting these features helps safeguard areas that already benefit the Lake and its tributary network and require little to no additional money and labor to maintain. For this reason, protecting such areas should be considered <u>high priority</u>. Enhancing these features is often a cost-efficient way of increasing the level of waterbody protection and should be considered a <u>medium priority</u>. Efforts should begin by targeting residential runoff from properties ringing the Lake and various sources from properties abutting the Bark River. Efforts may extend to adjacent properties as suitable. Implementation of this recommendation could involve the following steps:

- Continue to carefully control and limit development in SEWRPC-delineated primary environmental corridors to protect existing natural buffers, floodplains, and wetlands systems (see Map 2.20). Such development limitations are required under Chapter NR 121, "Areawide Water Quality Management Plans," of the *Wisconsin Administrative Code*, and they may be accomplished through local zoning.

- Continue to enforce zoning standards set forth in Chapter NR115, "Wisconsin's Shoreland Protection Program," of the *Wisconsin Administration Code* (i.e., 75 feet from the ordinary high-water mark along navigable waters) in the watershed.[184]

[184] *The Wisconsin Legislature enacted significant changes to shoreland zoning laws in the 2011, 2013, and 2015 legislative sessions. These changes have generally resulted in a more limited role for the WDNR and counties, and a greater role by the State legislature in directly establishing shoreland standards. Of particular importance are 2011 Wis. Act 167, 2013 Wis. Act 80, 2015 Wis. Act 41, 2015 Wis. Act 55, 2015 Wis. Act 167, and 2015 Wis. Act 391. Previously, county ordinances were required to meet minimum standards set by the WDNR, but counties could enact stricter standards. That began to change with the 2011 Wisconsin Act 170, which prevented counties from adopting stricter standards than those in NR 115 for nonconforming structures and substandard lots. Since 2011, the trend of enhancing the role of the State legislature in the development of shoreland zoning has continued. For example, some of the more stringent standards adopted by counties, such as setbacks in excess of 75 feet, are no longer valid. Currently, under 2015 Wis. Act 55, a shoreland zoning ordinance may not regulate a matter more restrictively than it is regulated by a State shoreland-zoning standard unless the matter is not regulated by a standard in Chapter NR 115, "Wisconsin's Shoreland Protection Program," of the* Wisconsin Administrative Code*. (Examples of unregulated matters may involve wetland setbacks, bluff setbacks, development density, and stormwater standards.) In addition, under Act 55, a local shoreland zoning ordinance may not <u>require</u> establishment or expansion of a vegetative buffer on already developed land through mitigation; counties must allow property owners to establish 35-foot wide "viewing corridors" within each 100 feet of shoreland buffer zone and allow multiple viewing corridors to run consecutively in cases where shorelines run in excess of 100 feet; and, whereas the impervious surfaces standard remains at no more than 15 percent of the lot area, sidewalks, public roadways, and areas where runoff is treated by a device or system or is discharged to an internally drained pervious area, must not be included in the calculation of impervious surface and there are exceptions to the 15 percent standard for highly developed areas. According to the Wisconsin Legislative Council, 2015 Wis. Act 41 "authorizes towns to enact zoning ordinances that apply in shorelands, except that it generally prohibits a town zoning ordinance from imposing restrictions or requirements with respect to matters regulated by a county zoning ordinance that affect the same shorelands.*

- Provide information to lake and river shoreland property owners and landowners along mapped tributaries. This information should describe the benefits that near-shore aquatic and terrestrial buffers provide to waterbodies and help encourage landowners to protect buffers where they still occur and enhance, restore, or create buffers in other favorable areas where none remain. This information could include installation instructions and typical costs. Such programs would be most productive if accompanied by an incentive program that helps share the cost of installation or provides tax incentives.

  A few examples of programs that could enhance buffers in the watershed include installing rain gardens in residential areas, utilizing Farm Service Agency programs such as the Conservation Reserve Program and affiliated Conservation Reserve Enhancement Program in agricultural areas, and promoting adoption of soil health approaches throughout the watershed by sponsoring workshops and offering equipment for rent. Such initiatives use vegetation to decrease runoff volume as well as slow and filter stormwater runoff. If thoughtfully designed and located, groundwater recharge may also be enhanced. Grants may also be obtained for novel initiatives such as cropped buffers, where farmers receive a compensatory payment for growing crops that help filter runoff.

- Consider a shoreline best management practice and shoreline buffer enhancement program. This program could encourage developing rain gardens or buffers along shorelines. Rain gardens can sometimes be combined with buffer strips for added benefit. The WDNR Healthy Lakes & Rivers grant program could help fund some of these efforts.

- Consider obtaining conservation easements and continue purchasing wetlands, floodplains, and uplands in key areas. Buffers can be preserved indefinitely and can have their ecological value enhanced to improve their habitat, filtering, and hydrologic functions (see Appendix F).

➤ **Recommendation 3.2: Protect buffer, wetland, and floodplain function**
Control invasive species that threaten the ecological value of buffers, wetlands, and floodplains. Additionally, relax human-imposed constraints placed upon watercourses. These efforts should be considered a medium priority. An example invasive species recommendation is to monitor and control reed canary grass (*Phalaris arundinacea*) in wetlands and shorelands. This species, a two- to nine-foot-tall grass, spreads and quickly displaces native wetland plants that help treat polluted water and which provide valuable wildlife habitat. Consequently, a visual survey of appropriate watershed and shoreline locations is recommended to determine whether reed canary grass is a problem. If it is found to be an issue, the infestation should be promptly eradicated.[185] Human-imposed constraints commonly manifest themselves as stream reaches that are ditched, aggressively eroding, and debris choked, incised, and or diked. Such reaches should be targeted for naturalization.

➤ **Recommendation 3.3: Protect remaining woodlands**
Perhaps the largest threat posed to woodlands in Southeastern Wisconsin is the combined problem of 1) diseases and insects that destroy the native tree canopy and 2) invasive plants such as buckthorn (common buckthorn (*Rhamnus cathartica*) and glossy buckthorn (*Frangula alnus*)) that inhibit or prevent native tree regeneration. Introduced pests have attacked ash, elm, butternut, and oak species. New pests are on the horizon that target black walnut, beech, and other trees. Existing woodlands should be kept free of invasive plant species and actions can be taken to prepare the woodland for the arrival of pests. For example, increasing the diversity of tree species through careful stand management and/or planting can help assure that complete canopy loss does not occur in the future. Actively employing these recommendations should be assigned a medium priority. State programs are available to assist woodland owners with stand management, tax implications, and professional forestry advice.[186]

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[185] *Reed canary grass can be controlled through burning, modifying hydrology (e.g., flooding), tilling, grazing, mulching, shading (with tree and shrub plantings), manual removal, mowing, and/or chemical treatment. These methods are commonly used in appropriate combination. More information can be found at the following website: www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_035064.pdf.*

[186] *The following website provides an overview of WDNR forestry information and programs: dnr.wi.gov/topic/ForestLandowners.*

- **Recommendation 3.4: Maintain stormwater detention basins**
  This should be considered a high priority, especially given anticipated increases in urban land uses. Maintaining stormwater basins includes managing aquatic plants, removing and disposing of flotsam/jetsam, ensuring adequate water depth to settle and store pollutants, and actively and aggressively managing excess sediment. Specifications associated with the design of stormwater detention basins and maintenance requirements ensure that basins are functioning properly.[187] It is important to remember that stormwater detention basins occasionally require dredging to maintain characteristics that protect downstream waterbodies. Dredging frequency is highly variable and depends upon the design of the basin and the characteristics of the contributing watershed. Responsible regulatory entities should inspect the basins in a manner consistent with current practices; however, ensuring that the owners of these basins know the importance of meeting these requirements (through educational outreach) can help ensure continued proper functioning of the ponds. Coordinating with municipalities and neighborhood associations can play an important role.

- **Recommendation 3.5: Promote urban nonpoint source abatement**
  In addition to local stormwater ordinances and stormwater management planning, another cost-effective way to abate nonpoint source pollution is for all municipalities within the Nagawicka Lake watershed to work toward satisfying all conditions required by the WPDES MS4 discharge permitting process. This should be considered a high priority issue, with particular focus Lake direct tributary areas.

- **Recommendation 3.6: Promote native plantings in and around existing and new stormwater detention basins**
  Establishing native plants in these situations improves filtration of detention waters, reduces pollutant loading, and provide wildlife habitat. In addition, detention basin landscaping practices should be modified to reduce or eliminate fertilizing basin slopes should limit herbicide use and should focus cutting on invasive species. This practice should be considered a medium priority.

- **Recommendation 3.7: Combine riparian buffers with other structures and practices**
  A much higher level of pollution removal can be achieved by employing "treatment trains," where riparian buffers are combined with better-managed detention basins or new practices such as floating island treatments (see Figure 3.2), grassed swales, and infiltration facilities. Such layering of practices and structures is a more effective way to mitigate the effects of urban stormwater runoff than such practices being used in isolation. This action should be assigned a high priority.

- **Recommendation 3.8: Retrofitting existing and enhancing planned stormwater management infrastructure to benefit water quality**
  Water quality can benefit by extending detention times, spreading floodwater, and using features such as grassed swales to convey stormwater. Implementing such works requires close coordination with the municipalities within the Nagawicka Lake watershed. This should be considered a high priority.

- **Recommendation 3.9: Collect leaves in urbanized areas**
  This recommendation should be assigned a high priority. Leaves have been shown to be a very large contributor to total external phosphorus loading to lakes in urban settings. Stockpiling leaves in the street where they may be crushed and washed into the Lake or burning leaves in shoreline and ditch areas can create situations where a strong pulse of phosphorus is delivered to the Lake by late autumn rains. Residents should be encouraged to take advantage of yard waste collection and leaf disposal programs in existence in those municipalities in the watershed that conduct such programs.

- **Recommendation 3.10: Stringently enforcing construction site erosion control and stormwater management ordinances and creatively employing these practices**
  Ordinances must be enforced by the responsible regulatory entities in a manner consistent with current practices; however, local citizens can help by reporting potential violations to the appropriate authorities. This should be considered a high priority.

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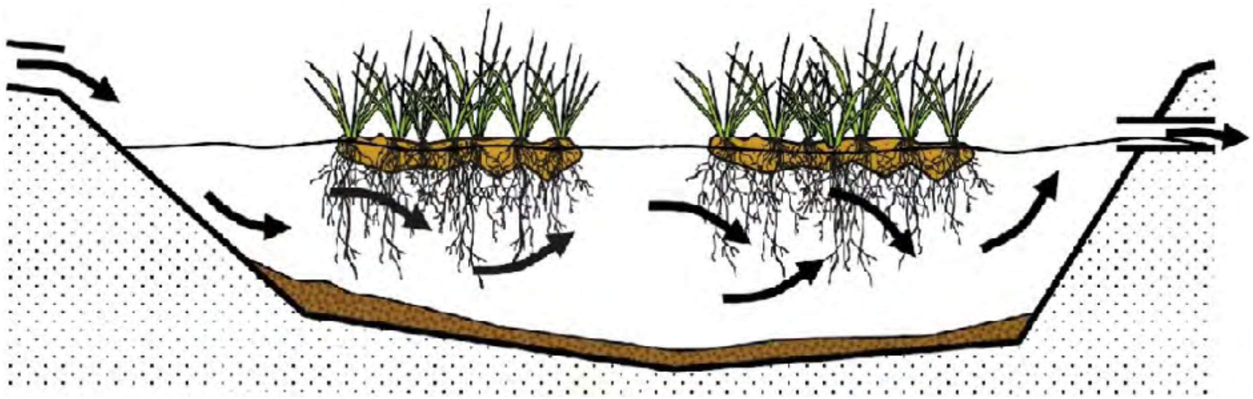
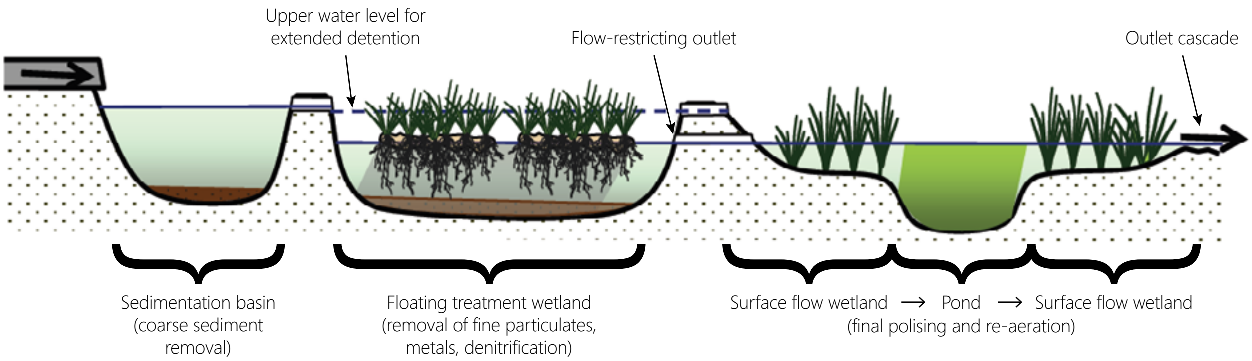
[187] *Technical standards for design and maintenance of wet detention basins and other stormwater management practices can be found at dnr.wi.gov/topic/stormwater/standards/postconst_standards.html.*

Figure 3.2
Floating Treatment Wetland Functional Schematic

Emergent plants are grown within a floating artificially constructed material within a wet detention stormwater basin. The roots are directly in contact with the water column and can intercept suspended particles. The roots also provide a high surface area for microbiological activity that aid in adsorbing pollutants.



Conceptual longitudinal cross-section through a "newly designed" stormwater treatment system incorporating floating wetlands, ponds, and surface flow wetlands (not to scale).



Source: I. Dodkins, A. Mendzil, and L. O'Dea, Floating Treatment Wetlands (FTWs) in Water Treatment: Treatment Efficiency and Potential Benefits of Activated Carbon, *FROG Environmental LTD., March 2014; T.R. Headley and C.C. Tanner, "Constructed Wetlands With Floating Emergent Macrophytes: An Innovative Stormwater Treatment Technology,"* Critical Reviews in Environmental Science and Technology, *42: 2261-2310, 2012 and SEWRPC*

Agricultural land use is forecast to transition to largely residential use. Whereas this may have been perceived as a negative to Lake health in the past, stormwater management practices used in urbanizing landscapes can tangibly lessen pollutant loads and positively modulate runoff volumes when compared to existing agricultural land use. Therefore, if carefully and stringently enforced, stormwater management practices in the watershed areas planned for urban development may reduce the overall pollutant loads to waterbodies and enhance dry weather baseflow. Moreover, future stormwater detention basins can be designed and located to enhance values beyond the requisite and site-specific pollutant trapping and runoff detention value. For example, if a detention pond is located adjacent to a natural area, a stormwater basin can provide valuable habitat function. Similarly, stormwater detention basins can be located in areas prone to contribute to groundwater recharge, helping sustain valuable groundwater-derived baseflow to local lakes, streams, and wetlands. Bioswales, unlined ditches, and a battery of other "green" stormwater management practices can add to the overall positive effect of modern stormwater management.

Sub-Basin Level Recommendations

Since some sub-basins bring more sediment and pollutants into the Lake system than others, it is important to develop specific goals to mitigate potential pollutant loading that reflect differences in each sub-basin or local physiography.

- **Recommendation 3.11: Prioritize pollutant load reduction practices by sub-basin pollutant loading**
  To help assure critical needs are addressed first, and that funds are efficiently invested, new infrastructure or active management practices that help reduce pollutant loads should be favored in areas that yield the most pollutants contributed per acre of watershed. Map 3.4 illustrates the prioritization of watershed sub-basins for pollutant load reduction. For non-agricultural infrastructure and active management practices, investment should be prioritized as follows:

  1. Sub-basins 7, 8, 10, and 11

  2. Sub-basins 2, 3, 4, 5, and 6

  3. Sub-basins 1 and 9

  For agricultural practices, areas closest to waterbodies and within floodplains should be prioritized (see Appendix E). Finally, practices that promote groundwater recharge should favor areas of high or very high groundwater recharge (see Map 3.1).

Shoreline Maintenance Level Recommendations

- **Recommendation 3.12: Maintain shoreline protection and prevent streambank erosion**
  As described in Chapter 2, most of Nagawicka Lake's shoreline is protected by "hard" (i.e., wood, metal, concrete) manmade riprap or bulkhead. Such structures can be effective means of protecting human manipulated shorelines from erosive wave action, especially along low banks area and shallow waters. Such structures are not permanent and need to be adequately maintained to continue to function as designed. However, shoreline protection also needs to protect waterbodies from excessive sediment, nutrient, and pollutant loads carried in runoff. As an alternative to hard structures, properly vegetated buffer strips are recommended.

  Shoreline property owners need to better understand how vegetated riparian buffers can both check shoreline erosion and reduce the amounts of sediment and pollutants reaching the adjacent waterbody. This is especially important in those areas where the shoreline is unprotected (e.g., where lawn is manicured to the water's edge). Map 2.27 locates specific areas around Nagawicka Lake where eroding and unprotected shoreline exist. In general, priority should be given to adding natural shoreline protection to areas that lack protection or are actively eroding, repairing, or maintaining already installed shoreline protection structures when and where feasible, installing "soft" shoreline protection such as a well-designed array of native vegetation, and expanding riparian buffers. These actions are considered high priorities.

- **Recommendation 3.13: Reduce refracted wave energy**
  Shorelines armored with concrete, steel, wood, and other straight and hard materials tend to reflect wave energy back into the Lake. This refracted energy eventually reaches another shoreline where it is either absorbed or again refracted back into the Lake. Such conditions can magnify the erosive power of waves. Many actions can be taken to reduce wave energy refraction. Examples include using irregular materials and surfaces that help absorb and dissipate wave energy, planting emergent or floating leaf plants to dissipate energy before it reaches the shoreline, and substituting hard shoreline armor for plants and woody structure. Perhaps the most practical way of approaching this issue is to require wave-energy absorbing features in new or repaired shoreline protection plans. This should be assigned a medium priority.

- **Recommendation 3.14: Encourage pollution source reduction efforts (best management practices) along shorelines**
  Such efforts would include developing goals consistent with the guidelines of the Healthy Lakes & Rivers Program.[188] These efforts are recommended as a high priority.

- **Recommendation 3.15: Enforce ordinances**
  Ordinances concerning building setbacks and mitigation measures should be enforced. This is recommended as a high priority.

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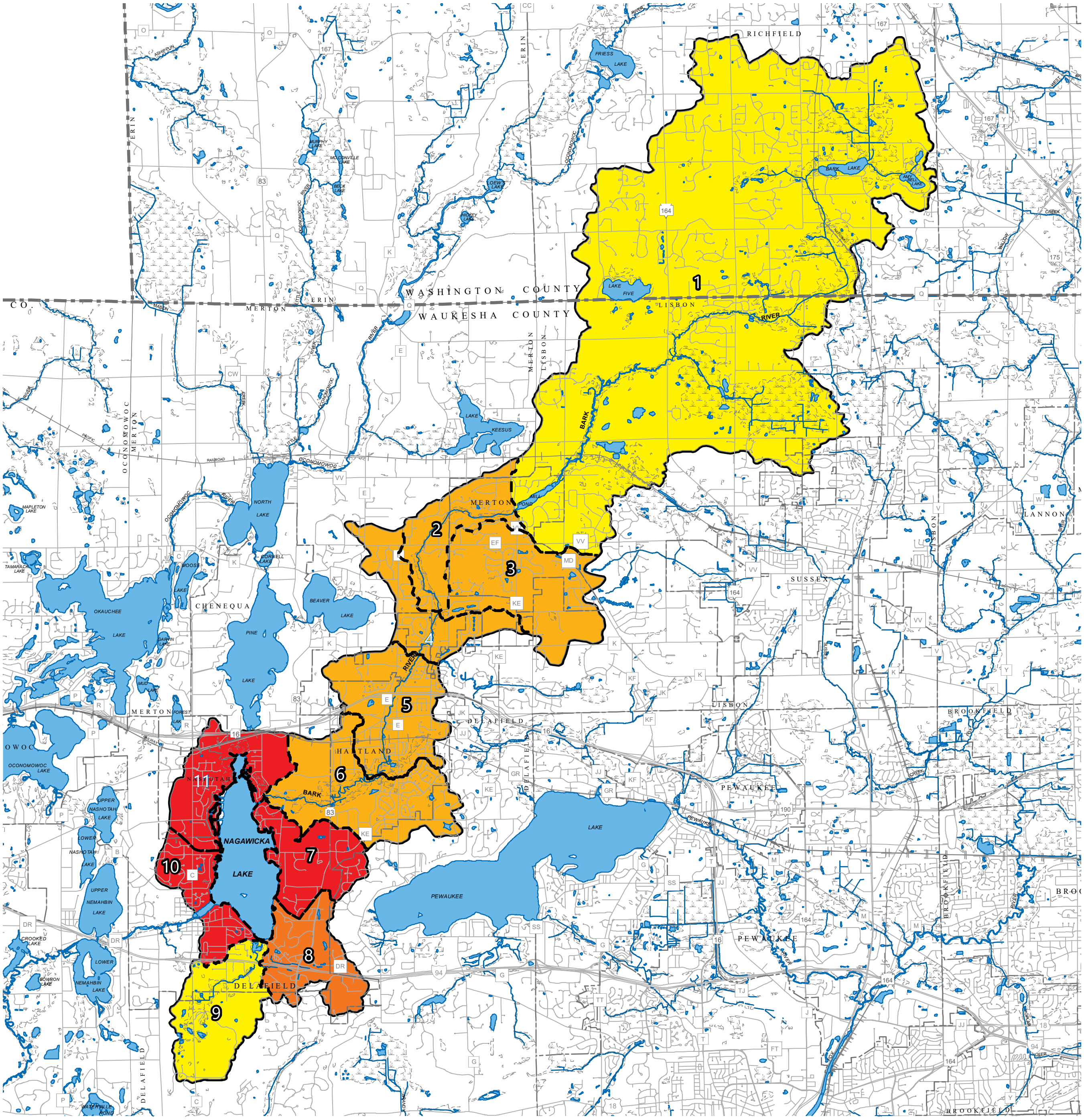
[188] *For more information on the Healthy Lakes & Rivers Program, see healthylakeswi.com.*

Map 3.4
Pollutant Load Reduction Project Prioritization by Watershed Sub-Basin



SUB-BASIN PROJECT PRIORITY

- VERY HIGH PRIORITY
- HIGH PRIORITY
- MEDIUM PRIORITY
- LOW PRIORITY

- SURFACE WATER
- STREAM
- WATERSHED BOUNDARY
- SUB-BASIN BOUNDARY
- WETLAND
- 1 SUB-BASIN NUMBER

N

0 0.5 1 2 Miles

Source: SEWPRC

3.5 AQUATIC PLANT MANAGEMENT

This section summarizes the information and recommendations needed to manage nuisance plant, Eurasian watermilfoil (EWM) (*Myriophyllum spicatum*), and curly-leaf pondweed (CLP) (*Potamogeton crispus*) growth in the Lake. Accordingly, it presents a range of alternatives that could potentially be used, and provides specific recommendations related to each alternative. The measures discussed focus on those that can be implemented by the LWC in collaboration with the WDNR and Lake residents. The aquatic plant management component of this report is limited to approaches that monitor and control nuisance aquatic plant growth in the Lake after growth has already occurred. Other sections in this chapter will describe other management strategies that can help prevent degradation of the Lake's water quality and aquatic plant community. Examples of such management actions include strategies to reduce phosphorus loads to the Lake and measures to prevent accidental introduction of new invasive plants and animals. In short, this section helps interested parties understand the particular plant management measures to be used in and around Nagawicka Lake and can be a valuable resource when developing future aquatic plant management efforts and requisite permit applications.

The individual recommendations presented below, and which collectively constitute the recommended aquatic plant management plan, balance three major goals:

- Improving navigational access within the Lake
- Protecting the native aquatic plant community
- Controlling CLP, EWM, and hybrid watermilfoil populations

Plan provisions also ensure that current recreational uses of the Lake (e.g., swimming, boating, fishing) are maintained or promoted. The plan recommendations described below consider common, State-approved, aquatic plant management alternatives, including manual, biological, physical, chemical, and mechanical measures.

Plant Management Recommendations for Nagawicka Lake

The most effective plans to manage nuisance and invasive aquatic plant growth rely on a combination of methods and techniques. A "silver bullet" single-minded strategy rarely produces the most efficient, most reliable, or best overall result. Several factors complicate aquatic plant management in the Lake. These factors include the following:

- Portions of WDNR-designated sensitive areas are located along highly developed shorelines
- The only fishing pier on the Lake accessible to people with disabilities and compliant with the Americans with Disabilities Act (ADA) of 1990 requirements is located in a WDNR-designated sensitive area
- Unmapped shallow water areas extending well into the Lake near the mouth of the Bark River are prone to nuisance aquatic plant growth and impede navigation near the center of the Lake[189]
- Plant beds near the mouth of the Bark River consistently host large populations of EWM and CLP

This plan recommends three primary aquatic plant management techniques, each of which must be adapted for unique conditions present in portions of the Lake. Recommended aquatic plant management elements include the following.

[189] *Due to outdated bathymetric information combined with implementation of dredging projects throughout Nagawicka Lake, actual water depths observed in the field must take precedence over mapped water depths when making real-time decisions. It is also important to note that the location and extent of dredging projects must be consistent with the WDNR-approved Chapter 30 Permit Application (Project I.D. 06D006), revised May 2008 for the City of Delafield, prepared by Foth Infrastructure & Environment, LLC.*

- Aquatic Plant Harvesting (Deep Cut, Top Cut, and Diver Assisted Suction Harvesting (DASH))
    - Access Lanes
    - Recreational Areas
    - Nearshore Areas
    - High-Use Sensitive Areas
    - Invasive Plant Control
    - Bark River Delta
    - Late Season Harvesting
- Manual Removal (Raking and Hand-Pulling)
    - Individual Property Owners
    - Collective Manual Removal Programs
- Early Spring Chemical Treatment
    - Invasive Plant Control
    - Navigation Lanes in Sensitive Area 1

These methods are combined to create the recommended Nagawicka Lake aquatic plant management program. Program elements are described in more detail below.

➤ **Recommendation 4.1: Aquatic plant harvesting to create access lanes**

This should be considered a high priority. As can be seen on Figures 3.3 through 3.6, harvesting is recommended to create access channels in areas of the Lake that host dense aquatic plant growth, impeding boat access to and within the main body of the Lake. The lanes should extend to open water (i.e., water about 10 feet deep) or a maximum of 300 feet from shore (a distance coinciding with the buoy line), whichever is closer to shore. The LWC currently uses an Aquarius Systems HM-420 VS harvester and acquired a new Inland Lake Harvester ILH7-450 for a 1-year trial period in 2018.[190] After this time, the use of two harvesters will be reevaluated (see Appendix G-harvester information for harvester specifications).

Harvesting in Sensitive Areas 1, 2, and 3 must leave a minimum of one foot of growing plant material at the Lake bottom. Access lanes in Sensitive Area 1 are to be 20 feet wide measured from the lakeward end of piers toward the center of the Lake (Figure 3.5). Harvesting in Sensitive Area 2 is restricted to access channels no greater than 20 feet wide down the center of the navigation channels (Figure 3.5). Harvesting in Sensitive Area 3 is restricted to a 30-foot-wide access lane to the "Kettle" and 20-foot maximum width access channels cut near the northeast and eastern shorelines.

A specific harvesting plan is proposed for Zastrow Bay on the Lake's east-central shoreline (Figure 3.6). Zastrow Bay may be harvested in three locations: the northwest, northeast, and southeast fingers of the Bay. Harvesting in the northwest finger will include a centrally located 40-foot-wide entry lane that then splits into a 30-foot-wide lane along the eastern shore and a 20-foot-wide lane along the western shore. Additionally, a 10-foot-wide access lane may be cut for the pier located on the southwestern shore. In the northeast finger of Zastrow Bay, a 20-foot-wide entry lane may be harvested into the

[190] *Mention of product names is for informational purposes and does not constitute an official endorsement by the Southeastern Wisconsin Regional Planning Commission.*

Figure 3.3
Nagawicka Lake Aquatic Plant Management Overview: 2017 – 2021

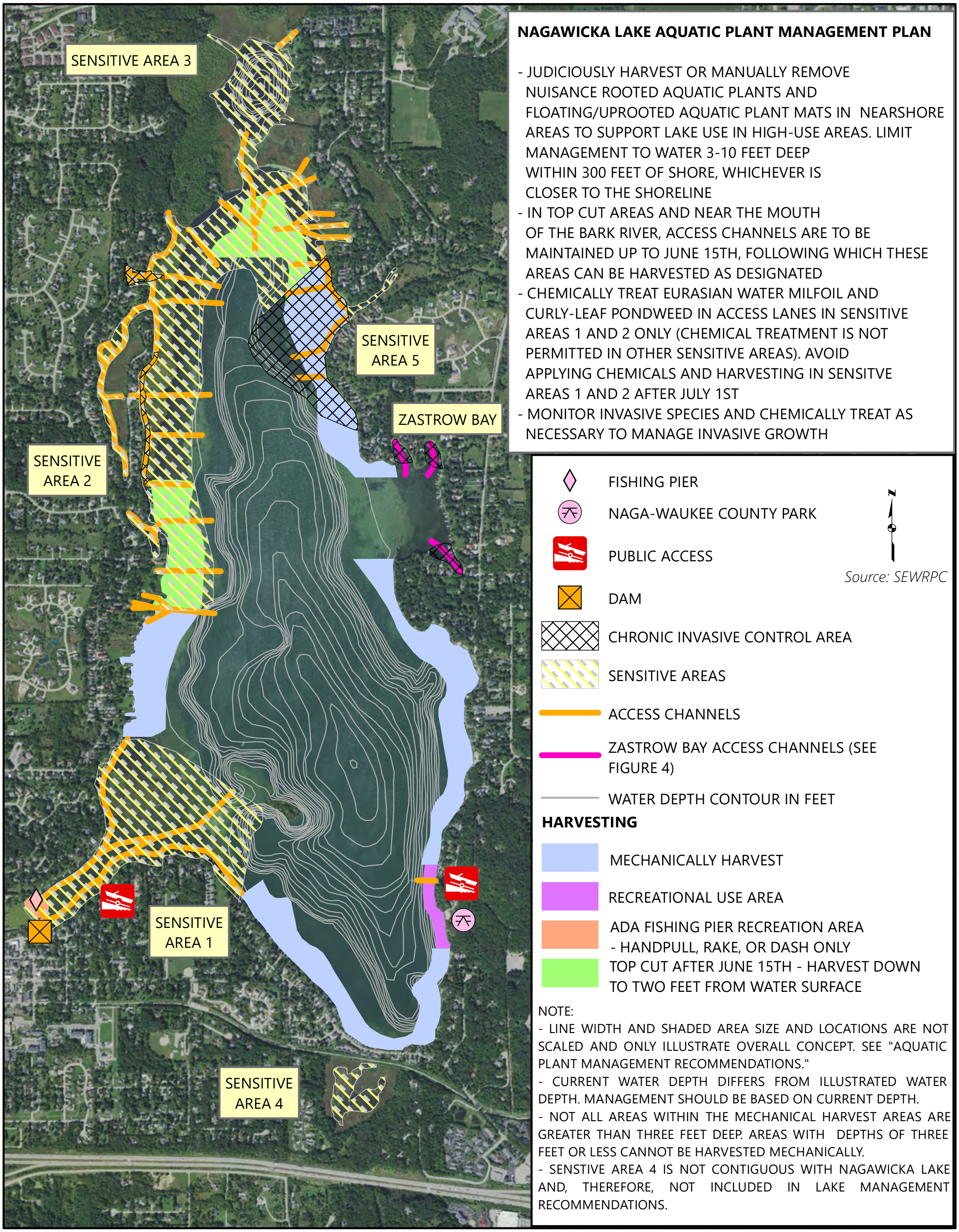


Figure 3.4
St. John’s Bay Aquatic Plant Management Overview: 2017 – 2021

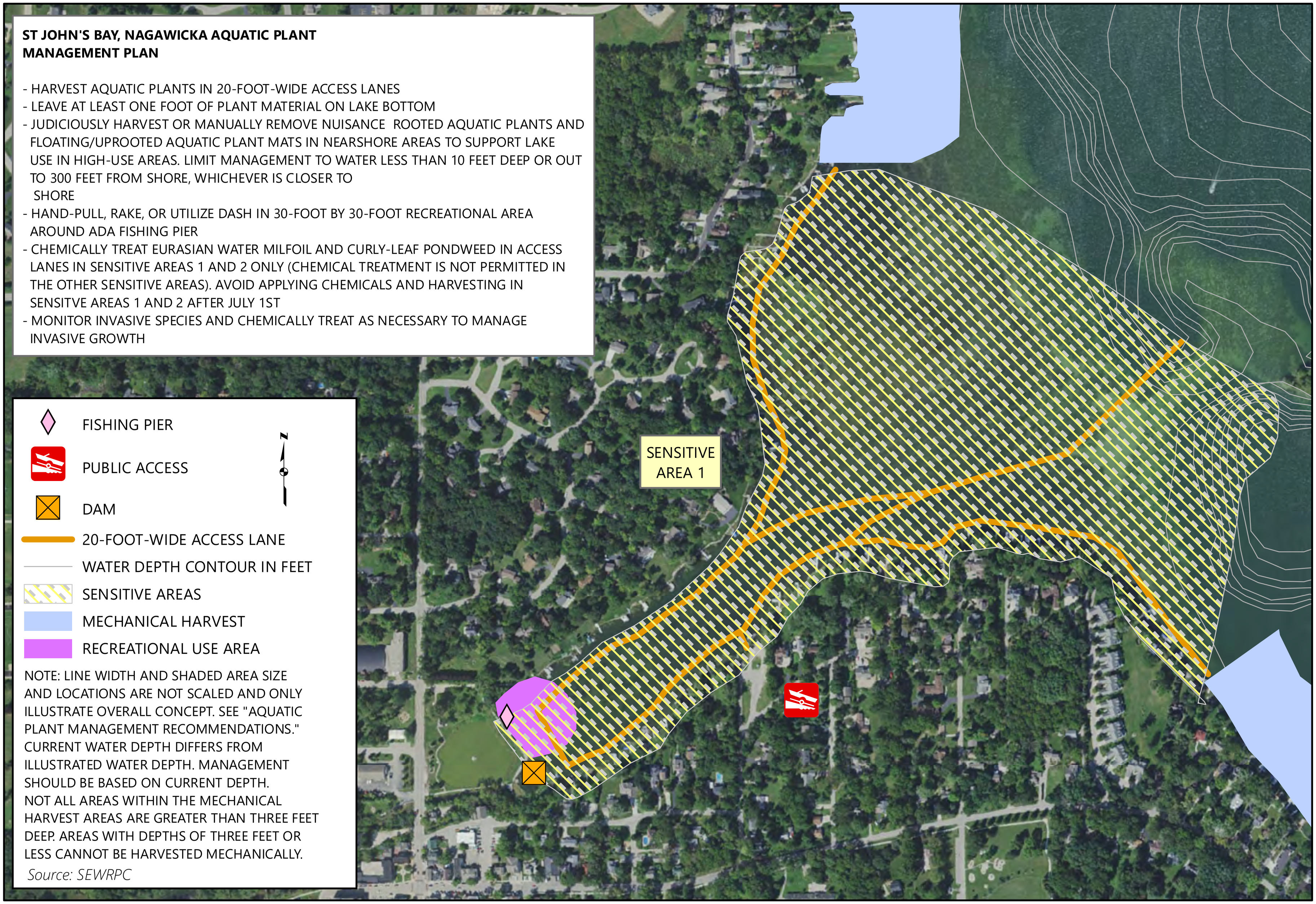
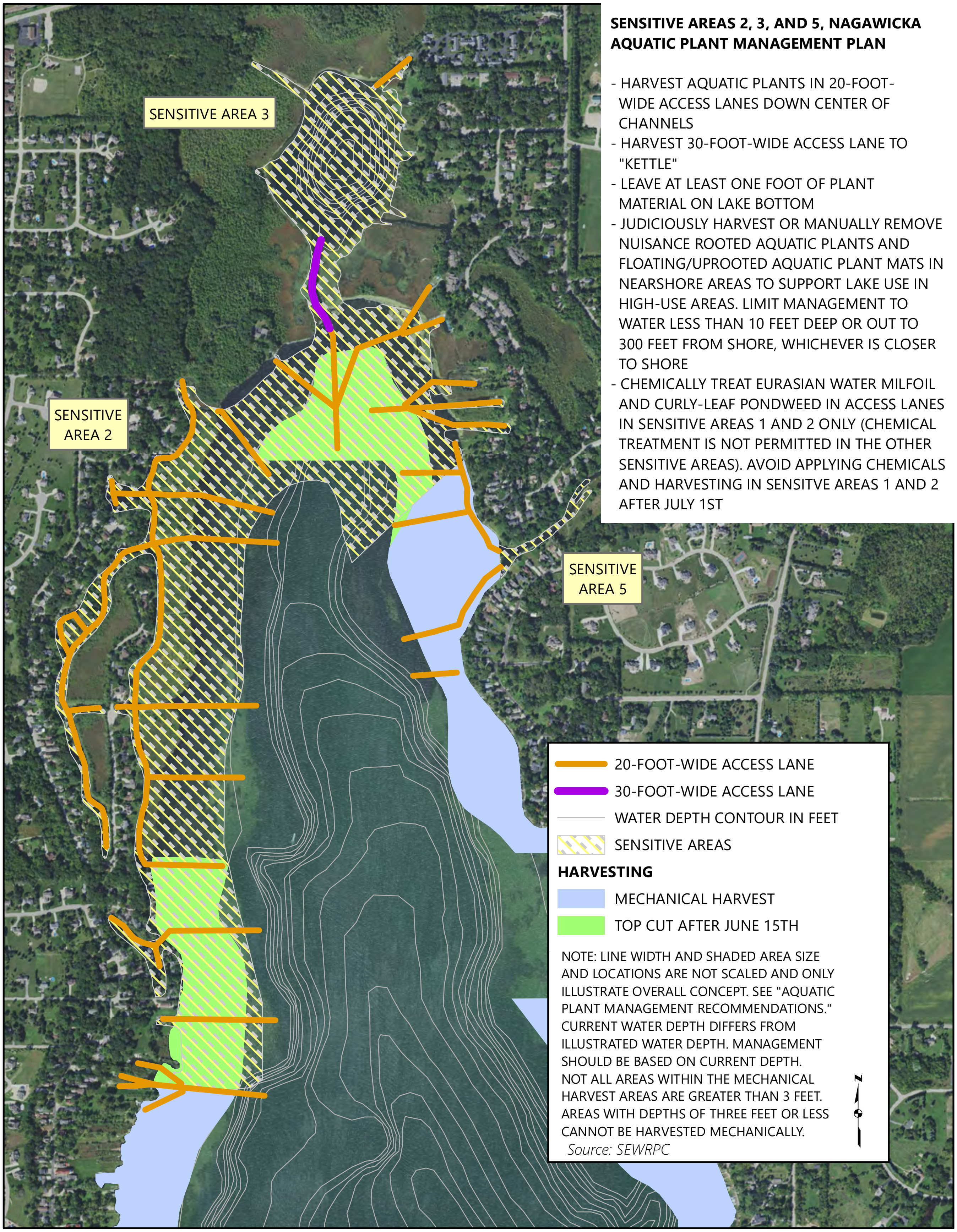
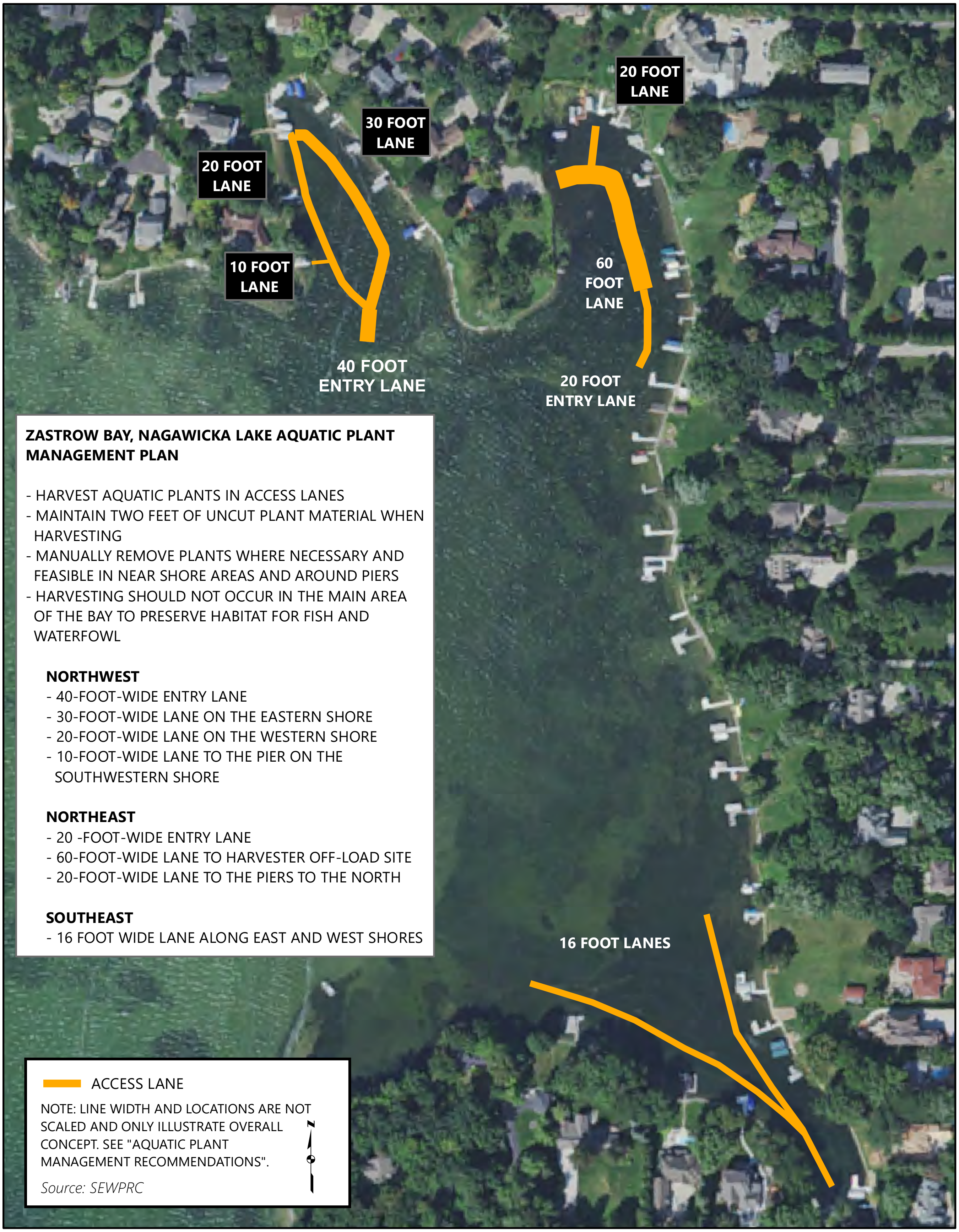


Figure 3.5
Sensitive Areas 2, 3 and 5 Aquatic Plant Management Overview: 2017 – 2021



Source: SEWRPC

Figure 3.6
Zastrow Bay Aquatic Plant Management Overview: 2017 – 2021



Source: SEWPRC

bay along the east shoreline that will curve into a 60-foot-wide lane to the harvesting off-load site. A 20-foot-wide access lane may be cut for pier access on the northcentral portion of the finger. Harvesting in the southeast finger of Zastrow Bay can include one 16-foot-wide access lane along the east side of the finger and one 16-foot-wide lane along the west side, with those lanes converging and terminating at the end of the finger. At least two feet of uncut living plant material must remain growing at the Lake bottom in each finger of Zastrow Bay. Plant roots must not be removed or disrupted. Harvesting should not occur in the main portion of Zastrow Bay to preserve a stable, healthy aquatic plant community for fish rearing, spawning, feed and cover, and a food source for waterfowl.

➤ **Recommendation 4.2: Continue aquatic plant harvesting to enhance recreational use**

A 30-foot-wide access channel may be harvested from the entrance to the Naga-Waukee County Park boat launch and may extend for a length of no more than 150 feet. No other harvesting may occur along the shoreline at Naga-Waukee Park. At least one foot of living plant material must remain attached to the Lake bottom after harvesting. Chemicals may be used in the early spring in areas too shallow to employ harvesters. This is recommended as a <u>low priority</u>.

Due to shallow water depth, no mechanical harvesting may occur around the ADA fishing pier in St. John's Bay. A 30-foot by 30-foot area may be removed around the ADA fishing pier using DASH (suction harvesting), hand-pulling, and/or raking. Water around this pier is reportedly extremely shallow, exacerbating the nuisance plant growth problem and limiting its value as a fishing pier. It may be wise to relocate this pier to a different publicly accessible area with deeper water near the shoreline (e.g., Naga-Waukee Park).

➤ **Recommendation 4.3: Harvest nearshore nuisance plant growth**

Nuisance plant growth refers to dense mats of plants growing within 18 inches of the Lake's water surface. Aquatic plants may be actively controlled to support desired Lake uses in high-use shoreline areas. Management must be limited to water depths between three and 10 feet or a maximum of 300 feet from shore, whichever is closer to shore. Uprooted/floating vegetation may be harvested and vegetation impeding navigation may be top cut but at least two feet of living rooted plant material must remain after top-cut harvesting. Aside from Zastrow Bay, ten-foot-wide access lanes may be cut from private piers to open water. As stated previously, no harvesting whatsoever shall occur within the main body of Zastrow Bay. These areas are shown in Figures 3.3 through 3.6 as "top cut" or "mechanical harvest." In top cut areas (which are located within WDNR-designated sensitive areas), nuisance plant growth can be cut to a depth up to two feet below the water surface and should not be harvested until after June 15th to preserve fish spawning habitat. In mechanical harvest areas, nuisance plant growth may be cut to a deeper depth, but at least one foot of vegetation and plant roots must remain attached to the Lake bottom. This recommendation is a <u>high priority</u>.

Plants will be harvested using the equipment described earlier in this section. Areas too shallow for harvester access may be manually harvested (discussed below) or mechanically harvested with a small, maneuverable, shallow-draft harvester (e.g., Inland Lakes ILH5x4-100—"Mini" Series or similar). Information regarding small, shallow draft harvesting equipment can be found in Appendix G. This information is supplied to illustrate general types of equipment now available on the market and is not an endorsement for any particular make or model. The LWC should thoroughly review and vet any equipment it intends to use, lease, or purchase to assure it best meets its unique needs and desires.

➤ **Recommendation 4.4: Deep-cut harvesting may occur in the Bark River delta in designated access lanes after September 30**

This harvest practice must leave at least one foot of rooted aquatic vegetation at the Lake bottom and must not remove plant roots. This recommendation is a <u>medium priority</u>.

➤ **Recommendation 4.5: Apply early spring chemical treatment in access channels only in Sensitive Areas 1 and 2 if nuisance plant growth impedes Lake access**

Sensitive Areas 1 and 2 are the only sensitive areas where chemicals may be used to control aquatic plants. Treatment should be limited to EWM- and CLP-infested areas in navigation lanes. If chemical treatment is used in Sensitive Areas 1 and 2, it should only occur in the early spring when human contact and risks to native plants are most limited, and not after July 1. A WDNR permit and WDNR staff supervision are required to implement this alternative. Lakeshore property owners must be notified of planned chemical treatment schedules and permit conditions before chemicals are applied to the Lake. This recommendation is a low priority.

- **Recommendation 4.6: Control growth of invasive plant species**
  This recommendation is a high priority. While the 2016 aquatic plant survey did not reveal a need to actively control EWM or CLP, these plants should still be monitored and managed as described below. As aquatic plant community species change, the need for management changes. This is particularly true around the mouth of the Bark River where EWM and CLP are known to be dense, and in heavily used shallow areas. Populations should be controlled with top-cut harvesting and early spring chemical treatments.

  Fall chemical treatments historically have been utilized to control the resurgence of late season CLP populations around the Bark River. The WDNR is currently studying effectiveness of fall chemical treatment under certain conditions. The LWC should consider these results when available to decide if fall chemical treatment is appropriate for the Lake.

- **Recommendation 4.7: Manually remove nuisance plant growth in nearshore areas**
  This recommendation should be considered in areas too shallow, inaccessible, or otherwise unsuitable for other plant control methods. "Manual removal" is defined as aquatic plant control using hands or hand-held non-powered tools. Given what is known of plant distribution, this option is given a medium priority. Riparian landowners need not obtain a permit to manually remove aquatic plants if they confine this activity to a 30-foot width of shoreline (including recreational use areas such as piers) that does not extend more than 100 feet into the Lake and if they remove all pulled plant materials from the Lake.[191] A permit is required if the property owner lives adjacent to a sensitive area or if the LWC or other group actively engages in such work on the owner's behalf.[192] Prior to the "raking/hand-pulling" season, an educational campaign should be help assure that shoreline residents appreciate the value of native plants, understand the relationship between algae and plants (i.e., more algae will grow if fewer plants remain), have basic aquatic plant identification skills, and are familiar with the specifics about the actions they are allowed to legally take to "clean up" their own shoreline.[193]

Figures 3.3 through 3.6 illustrate the overall aquatic plant recommendations for Nagawicka Lake.[194] To assure sustainable recreational use and the long-term health of the Lake, the following conditions apply to all aquatic plant harvesting practices and have a high priority.

- **Recommendation 4.8: Harvesting must maintain, at minimum, one foot of living rooted aquatic plant material after harvesting**
  No plant roots may be removed as removal damages native plant communities and stirs sediment into lake water.

- **Recommendation 4.9: Maintain and operate harvesting equipment in conformance with manufacturer's recommendations**
  Specifications of the new harvester are included in Appendix G. For example, never operate the harvester in water shallower than the maximum draft range of the harvester (e.g., 20 inches for the ILH7-450 Aquatic Weed Harvester) and never operate with the cutter head or paddle wheels at or near the lake bottom.

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[191] *The manual removal area limitation for nearshore aquatic plants applies to shorelines where native plants are present. The removal area limitation does not apply to areas populated solely with nonnative and invasive plants.*

[192] *If a lake district or other group wants to remove invasive species along the shoreline, a permit is necessary under Chapter NR 109, "Aquatic Plants: Introduction, Manual Removal and Mechanical Control Regulations," of the* Wisconsin Administrative Code, *as the removal of aquatic plants is not being completed by an individual property owner along his or her property.*

[193] *Commission and WDNR staff could help review documents developed for this purpose.*

[194] *Line width and locations are not scaled and only illustrate overall concept. The actual size, orientation, and depth of plant management activities depend upon sensitive area restrictions and permit conditions and site-specific factors. Site-specific factors include the composition of the plant community, water depth, shoreline configuration and obstacles, and other factors.*

- **Recommendation 4.10: Inspect all cut plants for live animals and immediately return live animals to water**

  A second staff person equipped with a net should accompany and assist the harvester operator. Animals can be caught in the harvester and harvested plants, particularly when cutting large plant mats. Consequently, carefully examine cut materials to avoid inadvertent harvest of fish, crustaceans, amphibians, turtles, and other animals.

- **Recommendation 4.11: Avoid harvesting in the early spring as much as possible**

  This benefits the Lake's fishery by avoiding disturbing spawning fish**.** Studies suggest that harvesting activities can significantly disturb the many fish species that spawn in early spring.

- **Recommendation 4.12: All harvester operators must successfully complete training course to help ensure adherence to harvesting permit specifications and limitations**

  Completing training helps assure adherence to harvesting permit specifications and limitations. The regional WDNR aquatic invasive species coordinator and/or the City of Delafield's Public Works Department should provide training to all summer harvester operators. At a minimum, training should cover the following:

  - Explain "deep-cut" versus "shallow-cut" techniques and when to employ each in accordance with this plan
  - Review of the aquatic plant management plan and associated permits with special emphasis focused on the need to restrict cutting in shallow areas
  - Discuss equipment function, capabilities, limitations, hazards, general maintenance, and the similarities and differences between the various pieces of equipment they may be expected to operate
  - Help operators identify boundaries of WDNR-designated Sensitive Areas and familiarity with special regulations pertaining to these areas
  - Assure that operators can confidently identify aquatic plant and understand the positive values such plants provide to the Lake's ecosystem, which in turns encourage preservation of native plant communities
  - Reaffirm that all harvester operators are legally obligated to accurately track and record their work for inclusion in permit-requisite annual reports.

  Additionally, the training program should integrate other general and job-specific content such as boating navigational conventions, safety, courtesy and etiquette, and State and local boating regulations. Other topics salient to this course include first aide training, safety training, and other elements that promote safe, reliable service.

- **Recommendation 4.13: Continue plant pickup program and encourage shoreline resident participation**

  Harvesting, boat motors, and navigation can fragment plants. Plant fragments may float in the Lake, accumulate on shorelines (particularly the northeastern shoreline), and help spread undesirable plants. The harvesting program should continue to include a comprehensive plant pickup program that all residents can use. This helps assure that harvesting does not create a nuisance for Lake residents. The program typically includes residents raking plants, placing them in a convenient location accessible to the harvester (e.g., the end of a pier), and regularly scheduled pickup of cut plants by the harvester operators. This effort should be as collaborative as practical and harvester operators should consider focusing pickup efforts in the northeastern shoreline areas after weekends because plant fragments tend to preferentially accumulate in these areas on account of prevailing wind patterns. In addition, pickup should focus on the outlet dam area, where floating plant fragments have accumulated and may be passing through the outlet dam, as noted in Chapter 2. Installing a shallow net or cable across the bay in front of the dam may help catch floating plant fragments before they reach the dam's outlet works.

- **Recommendation 4.14: All plant debris collected from harvesting activities must be collected and properly disposed at designated disposal sites**
  Map 3.5 locates designated disposal sites; however, if requested, the City of Delafield also delivers harvested plants to residents, contractors, farmers/gardeners, landscapers, and others. Such disposal areas are not mapped. Aquatic plant material may not be deposited within identified floodplain and wetland areas.

Native Plant Community and Invasive Species Recommendations

A number of actions should be taken to retain native aquatic plants whenever practical and focus control efforts on aquatic invasive plants. All are considered high priority. These recommendations include:

- **Recommendation 4.15: Protect native aquatic plants to the highest degree feasible through careful implementation of aquatic plant management and water quality recommendations**
  Nagawicka Lake supports a wide array of aquatic plant species that provide excellent habitat and are integral to the health of the Lake's ecosystems. Muskgrass growth is particularly beneficial as it enhances marl formation and attendant sequestration of phosphorus from the water column.

- **Recommendation 4.16: Actively manage invasive species to protect native plants and wildlife**
  Invasive species are highly damaging to native plant and wildlife communities and are a nuisance to Lake recreation. Consequently, active invasive species management is recommended. The most problematic invasive species currently in, or around, Nagawicka Lake are EWM, CLP, reed canary grass, and purple loosestrife (*Lythrum salicaria*). All of these may be treated using manual or chemical methods. Mechanical and chemical aquatic plant control methods should follow best management practices to avoid spreading invasive plants and to lower the stress imposed by invasive species on the native plant community. Purple loosestrife can be biologically controlled with purple loosestrife beetles.[195]

- **Recommendation 4.17: Avoid disrupting bottom sediment or leaving large areas of bottom sediment devoid of vegetation**
  Invasive species tend to thrive on disturbed lake bottom. Many invasive species aggressively colonize bare lake, creating an opportunity to spread invasive species or allow recolonization of treated areas. EWM in particular thrives in such areas. For this reason, care should be taken to remove vegetation judiciously and sensitively from problem areas.

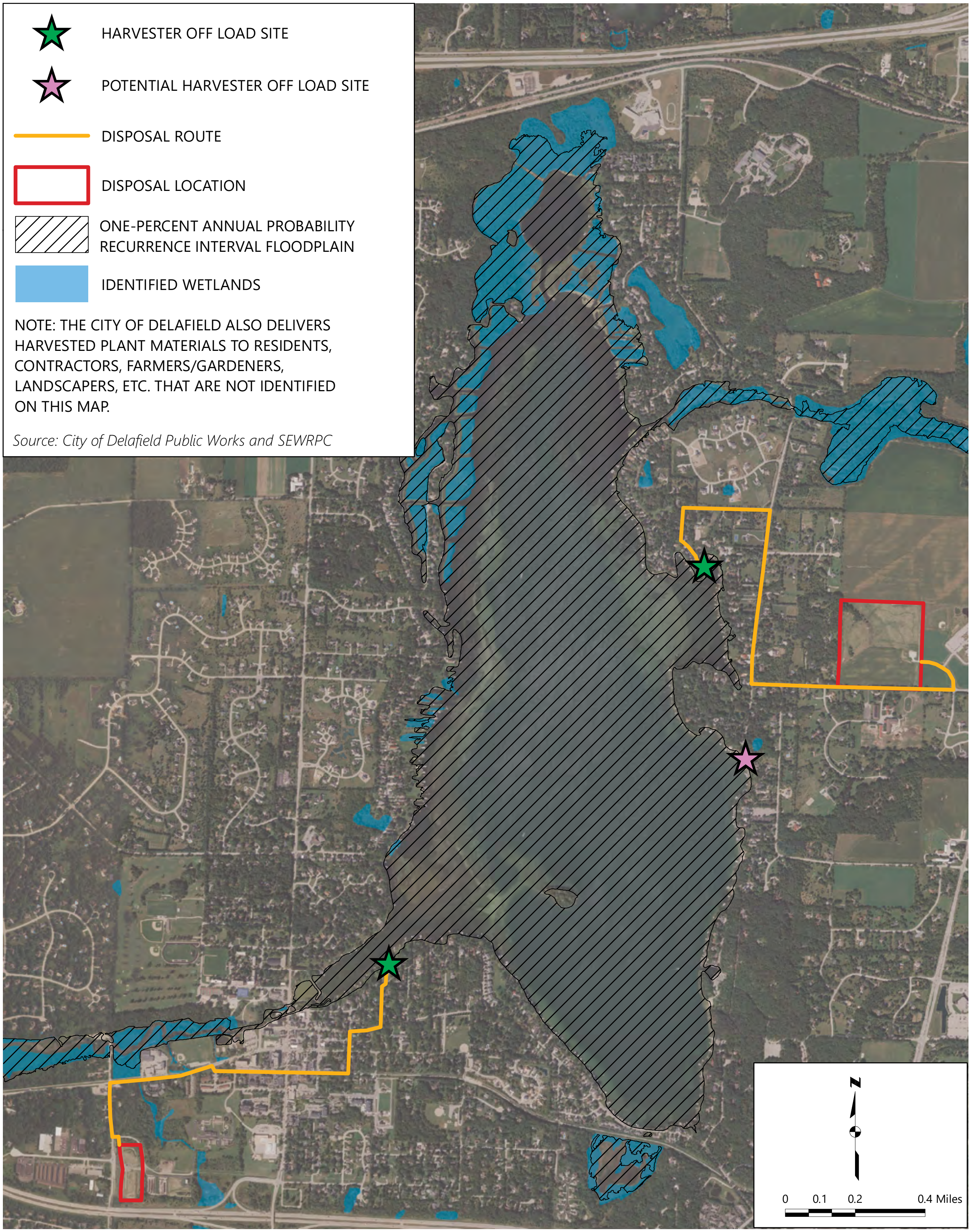
- **Recommendation 4.18: Implement chemical control methods in early spring**
  EWM, hybrid watermilfoil, and CLP grow earlier in the year than most native aquatic plants. Implementing control methods as early as practical in the spring can help minimize damage to native aquatic plant communities. Moreover, early spring chemical applications are more effective due to colder water temperatures, a condition enhancing the herbicidal effect and reducing the concentrations needed for effective treatment. Early spring chemical treatment also helps reduce human exposure through lower human contact with Lake water when water temperatures are still cold. Lastly, early season eradication of CLP helps lower production of turions (a dormant plant propagule), the dominant reproductive method of this plant.

- **Recommendation 4.19: Prevent introduction of new invasive species**
  Introduction of new invasive species is a constant threat. Preventing introduction is crucial to maintaining healthy lakes. Starry stonewort (*Nitellopsis obtusa*) (see Figure 2.77), as discussed in Chapter 2, is the newest invasive species posing a distinct risk to Nagawicka Lake particularly following its introduction into nearby lakes. To help decrease the chance of introducing new invasives the following recommendations are given high priority:

  - **Educate residents** how they can help prevent invasive species from entering the Lake.
  - **Enroll volunteers to participate in the Clean Boats, Clean Waters program** (a State program targeting invasive species prevention) to proactively encourage Lake users to clean boats and

[195] *More information about purple loosestrife beetles, and how to join a biocontrol program to grow and release beetles can be found on the WDNR website: dnr.wi.gov/topic/Invasives/loosestrife.html.*

Map 3.5
Mechanical Harvesting Disposal Site Locations, Off-Load Sites, and Haul Routes, Nagawicka Lake: 2017 – 2021



equipment before launching and using them in Nagawicka Lake.[196] This will help lower the probability of invasive species entering the Lake.

- **Target launch sites.** Since boat launches are likely entry points for alien species, boat launch sites should be targeted for focused aquatic plant control.

- **Take immediate action to evaluate and eradicate newly identified invasive species.** If a new alien species infestation is found in the Lake, efforts to eradicate the new species should immediately be evaluated and, if possible, be employed to help prevent establishment. The WDNR has funding that can aid in early eradication efforts, particularly as it pertains to aquatic plants (Table 3.2). Therefore, citizen monitoring for new invasive species is recommended. The Wisconsin Citizen Lake Monitoring Network (CLMN) provides training to help citizens participate in these efforts.

- **Re-evaluate the aquatic plant management plan every five years.** This requires a new point-intercept survey and thoughtful re-examination of aquatic plant species composition and abundance.

Finally, as described in water quality sections of this report, excessive nutrient concentrations promote nuisance-level abundance and growth of aquatic plants. Accordingly, efforts to improve water quality – which often go hand-in-hand with improving the overall quality of the Lake and its watershed – can also reduce the amount of aquatic plant growth in the Lake. Consequently, implementing the recommendations highlighted in Section 3.3, "Water Quality" is an important facet of overall aquatic plant management and is assigned a high priority.

3.6 CYANOBACTERIA AND FLOATING ALGAE

Excessive and/or toxic algae is presently not a priority issue of concern in Nagawicka Lake. To maintain desirable algal populations, this section recommends monitoring algal growth, helping Lake residents recognize and respond to excessive/toxic algae, and taking management actions that help prevent undesirable algal growth in the future. Recommendations consistent with this approach are listed below.

➤ **Recommendation 5.1: Control Lake water phosphorus concentrations**
Algal growth in Nagawicka Lake is limited by phosphorus availability. Several techniques are discussed in the Section 3.3, "Water Quality," to help maintain or reduce Lake water phosphorus concentration. Lower phosphorus concentrations generally decrease the potential for algal blooms. Implementing these recommendations helps the Lake maintain healthy algal populations. Implementing actions that help control Lake water phosphorus concentrations are therefore assigned a high priority.

➤ **Recommendation 5.2: Continue to monitor algal abundance**
This effort should focus on monitoring chlorophyll-*a*, as was described in the water quality monitoring recommendation (high priority). If large amounts of suspended or floating algae are found in the future (e.g., "pea soup" green water), samples should be collected to allow algal types to be identified. This can be considered a low priority at present, but if algae become abundant, it should be elevated to a high priority. Algal identification helps determine if abundant algae is a toxic strain.

➤ **Recommendation 5.3: Warn residents not to enter water during algal blooms**
This should be considered a high priority unless testing positively confirms the absence of toxic algae. Therefore, methods for rapidly communicating unhealthful water conditions unconducive to body contact should be developed.

➤ **Recommendation 5.4: Maintain or improve overall water quality**
Implementing recommendations provided in Section 3.3, "Water Quality" to improve water quality and reduce the risk of algal blooms developing. This should be assigned a high priority.

[196] *Further information about Clean Boats, Clean Waters can be found on the WDNR website at: dnr.wi.gov/lakes/cbcw.*

Table 3.2
Example WDNR Grant Programs Supporting Lake Management Activities

Category	Program	Grant Program	Maximum Grant Award	Minimum Grantee Match (percent)	Application Due Date
Water	Surface Water Grants	Aquatic Invasive Species (AIS) Prevention and Control	Clean Boats, Clean Waters: **$24,000**	25	November 1
			Established Population Control: **$150,000**	25	November 1
			Early Detection and Response: **$25,000**	25	Year-Round
			Research and Development annual funding limit: **$500,000**	25	November 1
		Surface Water Education	**$5,000** per project **$50,000** per waterbody	33	November 1
		Surface Water Plan	**$10,000**	33	November 1
		Comprehensive Management Plan	**$25,000**	33	November 1
		County Lake Grant	**$50,000**	33	November 1
		Ordinance Development	**$50,000**	25	November 1
		Management Plan Implementation	Lakes: **$200,000** Rivers: **$50,000**	25	November 1
		Healthy Lakes & Rivers	**$1,000** per practice **$25,000** per waterbody	25	November 1
		Surface Water Restoration	Lakes: **$50,000** Rivers: **$25,000**	25	November 1
		Land Acquisition and Easement	Lakes: **$200,000** Rivers: **$50,000**	25	November 1
	Citizen-Based Monitoring Partnership Program	--	**$5,000**	None	Spring
	Targeted Runoff Management	--	Small-Scale: **$225,000**	30	May 15
			Large-Scale: **$600,000**	30	May 15
	Urban Nonpoint Source & Stormwater Management	--	Planning: **$85,000** Property Acquisition: **$50,000** Construction: $**150,000**	50	May 15
Conservation and Wildlife	Knowles-Nelson Stewardship Program	Habitat Areas	--	50	March 1
		Natural Areas	--	50	March 1
		Streambank Protection	--	50	March 1
		State Trails	--	50	March 1
Boating	Boat Enforcement Patrol	--	Up to **75% reimbursement**	None	Various
	Boating Infrastructure Grant	--	Up to **$200,000 per state**	50	June 1
Recreation	Knowles-Nelson Stewardship Program	Acquisition and Development of Local Parks	--	50	May 1
		Acquisition of Development Rights	--	50	May 1
		Urban Green Space	--	50	May 1
		Urban Rivers	--	50	May 1
	Sport Fish Restoration	Boat Access	Varies annually	25	February 1
		Fishing Pier	Varies annually	25	October 1

Note: This table incorporates information from NR 193, which was made effective on June 1st, 2020. More information regarding these example grant programs may be found online at the following address: dnr.wi.gov/aid/grants.html. Additional federal, state, and local grant opportunities are available. Eligibility varies for each grant program.

Source: Wisconsin Department of Natural Resources and SEWRPC

➤ **Recommendation 5.5: Maintain a healthy aquatic plant community to compete with algal growth**
This can be promoted by implementing recommendations provided in Section 3.5, "Aquatic Plant Management." This should be assigned a high priority.

Implementing the above recommendations will help prevent excessive algal growth in Nagawicka Lake and should not preclude or significantly inhibit Lake use. If future monitoring reveals excessive or greatly increased algal growth, or should toxic algae be identified, these recommendations should be reevaluated (high priority). Reevaluation should include rethinking all relevant Lake management efforts.

3.7 FISH AND WILDLIFE

Fish and wildlife depend upon the Lake's health. Abundant and healthy fish and wildlife increases the Lake's recreational value, aesthetic appeal, overall enjoyment by humans, and the functionality of the Lake as an ecosystem. To enhance fish and wildlife quality and abundance within the Nagawicka Lake watershed, the following recommendations are made:

➤ **Recommendation 6.1: Understand fishery information, actively participate in the WDNR's planning processes, and support management recommendations**
Many recommendations were made by the WDNR as part of the most recent published fishery evaluation.[197] Examples include the following actions.

- Transition to a more restrictive walleye length and bag limit to protect females for multiple spawning seasons and potentially increase natural recruitment
- Convert from stocking small fingerling to large fingerling walleyes to increase survival and overall adult abundance
- Monitor walleye population for contribution of stocked versus naturally reproduced fish within each year class
- Continue regular stocking of large fingerling northern pike to increase survival and improve overall abundance
- With high mortality rates above the 26-inch minimum size limit, restrict angler harvest to one northern pike per day with a 32-inch minimum length limit
- Continue to monitor bass and panfish populations through catch rates, average sizes, and abundance estimates
- Monitor white sucker population and spawning success because of their importance as a forage species for gamefish
- Protect and improve habitat and water quality to promote diverse and healthy fish communities

The LWC may be able to provide the WDNR with information useful to fish management strategies. For example, The LWC could act as an avenue to report observed spawning areas, creel reports, angler pressure, baitfish and forage abundance, and other conditions. Supporting WDNR initiatives should be given a high priority.

➤ **Recommendation 6.2: Protect valuable in-Lake fish habitat and avoid disturbing vulnerable fish**
Fish require a variety of habitats to successively engage in all life-cycle critical functions. For example, the places where fish breed may be very different than those where those fish feed. Fish often enter shallow water and may be quite vulnerable to harm at certain times of the year. While the types of habitat vary by season and by fish species, a few types of habitat are clearly related to preserving populations of popular

[197] *B. Heussner, S. Gospodarek, and A. Notbohm (WDNR),* Comprehensive Survey Report of Nagawicka Lake – Waukesha County, *August 13, 2013.*

fish. For example, shallow sandy and gravelly areas in the Lake are important to spawning bass and many panfish; these areas should be protected and left unmolested during spawning season. The health of the bass and panfish fishery can be promoted by educating the public to limit excessive human activity in such areas during spawning periods. WDNR fisheries staff can help the LWC identify the locations of these areas and the timing of protective measures. Another example of a pre-emptive strategy is to take action to prevent excessive sedimentation and water temperatures in the Bark River, conditions that could hinder the stream's valuable contribution to naturally reproduced fish stocks. Activities such as these examples should be considered a high priority.

- **Recommendation 6.3: Mitigate water quality stress on aquatic life and maximize areas habitable to desirable fish**

The primary ongoing in-Lake issue in this category is the low and supersaturated oxygen saturation values found in the Lake during some seasons at certain depths. Excessive Lake fertility likely is the primary contributor to near-surface oxygen supersaturation and deep-water anoxia. Therefore, measures that improve water quality can meaningfully promote health fish populations and should be given a high priority.

Since the Bark River is an important spawning and nursery area for the Lake's fish population, action should also be taken to protect water quality in the river. Perhaps the most pressing river threats are the loss of tree canopy to exotic pests (which could raise water temperature to undesirable ranges) and increasing salt concentrations. The water quality recommendations discussed earlier in this chapter call for measures to address these conditions Implementation of those recommendations should be considered a high priority. Other stressors may develop in the future (e.g., new invasive species and other water quality concerns) and conditions should be carefully monitored for their impact on aquatic life (medium priority).

- **Recommendation 6.4: Continue active management actions that safeguard and/or improve long-term water quality and may promote reintroduction of cisco (*Coregonus artedi*)**

This recommendation is a specific subset of the previous recommendation. The recommendations made in Section 3.2, "Hydrology/Water Quantity," Section 3.3, "Water Quality," and Section 3.4, "Pollutant Sources and Loads" synergistically provide conditions favoring a healthy and sustainable fishery in the Lake and River. Although it will take much time and devoted effort, and may prove elusive, conditions could theoretically sufficiently improve to provide conditions supporting a two-story fishery. If such conditions are achieved, consideration should be given to re-establishing cisco in the Lake. Although this goal is important, the long-term perspective and its reliance on success of many other management initiatives cause it to be assigned a low priority.

- **Recommendation 6.5: Identify and remove instream barriers to passage of fish and other aquatic organisms**

Even ephemeral streams, which only flow seasonally, often provide fish passage and two-way access to spawning and nursery grounds. The Bark River is a life-cycle critical resource to some fish species and is a favored resource for many others. Fish species known, or likely, to use the Bark River include white suckers, walleye pike, northern pike, and other forage fish. Even small intermittent streams and ditches commonly provide important habitat function. For example, temporarily flooded grassy areas can be favored spawning areas for northern pike.

Barriers to fish and aquatic organisms are often categorized by permanence. Barriers that occasionally block fish passage, and which may be temporary in nature, include debris jams, sediment and railroad ballast accumulations, and channel overgrowth by invasive plants. Permanent barriers include many dams and culverts that are perched, too steep, too small, or too long. These barriers vary greatly in their ease and cost of removal and in the ability to meaningfully enhance aquatic ecological health and vitality through their removal.

A typical best management practice is executed in stages. First, a comprehensive inventory of potential barriers and the value of potentially inaccessible upstream habitat is completed. Next, the utility and condition of the structure or channel configuration is examined, and cost and benefits of remediation are estimated. Finally, a list of barrier remediation projects is produced. Projects identified as having the greatest ecological/societal benefit, lowest cost, and least logistical and public relation difficulties are prioritized for replacement, modification, or removal. Ozaukee County's Fish Passage Program is well developed and a good resource when establishing a fish passage program.[198] Identifying, prioritizing, and ultimately remediating fish passage barriers should be considered a high priority.

- **Recommendation 6.6: Improve in-Lake aquatic habitat by maintaining, encouraging, or installing large woody structure and/or vegetative buffers along shorelines**
  The vegetative communities along the Lake's shoreline have been simplified through traditional landscaping practices, a situation that reduces aquatic organism habitat value. Improving in-Lake habitat should be considered a medium priority**.** Implementing this recommendation could include educational or incentive-based programs to encourage riparian landowners to install "fish sticks"[199] (Figure 3.7), to allow fallen trees to remain in the water, and to develop buffer systems along the shoreline. WDNR grant money to install fish sticks projects is available on a competitive basis through the Heathy Lakes & Rivers program. Installing buffers will have the added benefit of deterring geese from congregating on shoreline properties and promoting improved water quality.

- **Recommendation 6.7: Adopt best management practices to improve wildlife habitat**
  This should be considered a medium priority, although this should increase to high priority if wildlife populations decline. The acceptance and employment of best management practices can be fostered through voluntary, educational, and/or incentive-based programs for properties adjacent to shoreline areas and by directly implementing these practices on public and protected lands. Some special interest NGOs (e.g., Walleyes for Tomorrow, Pheasants Forever, Ducks Unlimited, Trout Unlimited) foster habitat improvement projects and collaborate with land owners to install beneficial projects. As part of implementing this element, a list of best management practices and relevant NGOs should be compiled and provided to landowners.

- **Recommendation 6.8: Promote aquatic plant management plan implementation to avoid inadvertent damage to native species**
  Native aquatic plant species can help protect water quality and provide food and shelter for fish and wildlife. Avoiding inadvertent damage to native species is essential to maintaining a clean and healthy lake. This should be assigned a high priority.

- **Recommendation 6.9: Preserve, enhance, and expand wetland and terrestrial wildlife habitat while making an effort to maintain or enhance ecological connectivity between natural areas**
  This could be achieved by implementing the buffer and wetland protection recommendations provided in Section 3.4, "Pollutant and Sediment Sources and Loads." Benefit could also be accrued by hydraulically reconnecting floodplains to ditched and straightened tributary streams. These reconnected floodplains detain floodwater, improve water quality, may promote groundwater recharge, and provide seasonally wet areas that are of great value for a wide range of birds, fish, amphibians, insects, and terrestrial animals. This should be assigned a high priority.

- **Recommendation 6.10: Monitor the diversity and abundance of fish and wildlife**
  Monitoring would help future Lake managers detect change. Consequently, continued monitoring of fish populations and periodic recording of the types of animals found on and in the Lake and within its watershed is also a high priority. Monitoring data can be collected from government agencies, NGOs (e.g., Audubon Society), and from volunteers around the Lake and throughout the watershed.

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[198] *See website at www.co.ozaukee.wi.us/619/Fish-Passage.*

[199] *Natural shorelines generally have hundreds of fallen trees per mile along the shoreline. "Fish sticks" is a term coined for engineered installation of woody debris (logs) along lake shorelines to mimic these natural conditions. Generally, these projects involve anchoring logs into the shore so that the log is oriented perpendicular to the shoreline. See healthylakeswi.com/best-practices/#fish.*

Figure 3.7
Fish Sticks Projects Examples

Source: SEWRPC

3.8 RECREATIONAL USE AND FACILITIES

Nagawicka Lake supports diverse recreational activities. For example, the Lake is used for swimming, kayaking, water-skiing, high-speed boating, cruising, and fishing. Maintaining the Lake's ability to provide safe, high quality recreational pursuits is a priority issue. In conformance with this goal, the following recommendations are made.

- **Recommendation 7.1: Encourage safe boating practices and boating pressure on navigable portions of the Lake**
  Although use conflicts, safety concerns, and environmental degradation were not presented as issues of concern during the preparation of this plan, if boat densities increase to undesirable levels in the future, boating ordinances and regulations should be reviewed, and if necessary, modified. Such ordinances and regulations should be conscientiously enforced to help reduce the potential for problems related to boat overcrowding during periods of peak boat traffic. Since problems are not known to currently exist, but because boat densities are relatively high during peak periods, this should be considered a medium priority issue.

- **Recommendation 7.2: Maintain and enhance swimming opportunities by engaging in "swimmer-conscious" management efforts**
  This can be supported by adopting the aquatic plant management recommendations made earlier in this chapter (see Section 3.5, "Aquatic Plant Management"), improving water quality (Section 3.3, "Water Quality"), and controlling algae (see Section 3.6, "Cyanobacteria and Floating Algae"). This should be considered a medium priority issue.

- **Recommendation 7.3: Maintain and enhance fishing by protecting and improving aquatic habitat and ensuring the fish community remains viable**
  This recommendation can be achieved by implementing the aquatic wildlife recommendations provided in Section 3.7, "Fish and Wildlife." This is a medium priority issue.

- **Recommendation 7.4: Maintain public boat launch sites**
  Boat traffic on Nagawicka Lake is highly variable throughout the season and from weekday to weekend. The Lake is popular not only with boaters who live on the Lake, but also with those who trailer watercraft to the Lake. For this reason, launch site maintenance should be considered a high priority. This could include incorporating elements that help reduce the chance of spreading invasive species such as deploying trained volunteers to inspect boats and distributing literature (e.g., the Clean Boats, Clean Waters program) during high use periods. Such activities could help reduce the chance of spreading invasive species.

- **Recommendation 7.5: Existing boating regulations should be reviewed for compatibility with current conditions and expectations and ordinances should be conscientiously enforced**
  Although boating-related use conflicts, safety concerns, and environmental degradation were not presented as issues of concern during the preparation of this plan, if boat densities frequently increase to undesirable levels, boating ordinances and regulations should be reviewed, and if necessary, modified. Boat counts suggest that Nagawicka Lake is subjected to boat densities at the upper end or even slightly exceeding desirable use levels during peak use periods. Excessive boat density decreases the ability of the Lake to support a wide range of activities safely, sustainably, and satisfactorily. This means that the potential for use conflicts, safety concerns, and environmental degradation is slightly higher than desirable on Nagawicka Lake during some weekends and holidays. Existing boating ordinances should be reviewed with compatibility with current Lake conditions (medium priority). Given the variability of boating density, stringent ordinance enforcement should be considered a low priority for week days, but a high priority for summer weekends and holidays.

- **Recommendation 7.6: Consider increasing launch fees during peak use periods**
  Demand for power boating on Nagawicka Lake appears to exceed desirable supply at least occasionally during peak use periods. Common economic theory suggests that demand can be reduced if costs increase. Launch fees can include the basic price paid to launch a boat and other factors such as convenience (see *Wisconsin Administrative Code* NR 1, Natural Resources Board Policies, for more information. NR 1.91, Public Boating Access Standards, describes permissible fee structures in great detail). Certain changes can be made that both benefit the long-term health of the Lake and may place negative pressure on demand. Examples of such changes include the following:

  - Review water-based recreation ordinances and modify as necessary. Stringently enforce the regulations, especially during holidays and weekends. Grants are available to help offset the cost of revising and developing ordinances and help defray the cost of water patrols.

  - Maintain motorized boat launch fees at the maximum permissible rate during weekends and holidays. Consider launch surcharges (such as the following), particularly on weekends and holidays, to adjust fees:

    - Twenty per cent surcharge for launch sites with toilet facilities. Potentially also apply to weekday rates to enhance revenue available for providing weekend/holiday launch attendants.

    - Large boat surcharges. An attendant would need to be on site for effective application. Allowable large boat surcharges are 30 percent for boats 20 to 26 feet long, and 60 percent for boats longer than 26 feet.

    - Have an attendant on duty during all summer weekends and holidays. The attendant's primary duty would be to implement Clean Boats, Clean Waters watercraft inspections and distribute literature to help Lake users understand invasive species issues. A surcharge of 20 percent may be charged when an attendant is on duty, and the attendant can also be responsible for launch surcharges for large boats.

      Increasing launch fees is assigned an overall medium priority, the implementation of which is dictated by the desires of the boat launch owner (Waukesha County) and the needs and perceptions of Lake users.

3.9 PLAN IMPLEMENTATION

Some recommendations can be implemented through regulation while others involve proactively implementing new management efforts. Both are discussed in the following text.

Regulations

Relative to this plan, regulatory implementation refers to maintaining and improving water quality, water quantity, wildlife populations, and other objectives through application of local, State, and Federal rules and laws. A number of regulations already govern activities within the Nagawicka Lake watershed including zoning and floodplain ordinances, boating and in-Lake ordinances, groundwater use, and State regulations related to water quality. These regulations already help protect the Lake by mitigating pollution, encouraging or limiting development to projects which consider the large picture perspective, and encouraging use of best management practices.

Local Ordinances

Zoning ordinances dictate where development can take place, the types of development allowed, and the technical standards that need to be met for development to proceed. Consequently, zoning can be a particularly effective tool to protect buffers, wetlands, uplands, shorelands, and groundwater resources if environmental goals are integrated into ordinance development, formulation, and enforcement. One way to integrate environmental considerations is for local zoning authorities and other regulatory agencies to recognize SEWRPC-designated environmental corridors (see Figure 3.8). Environmental corridors can be integrated into conservancy zoning district regulations to help determine where development is permitted and not permitted, and to determine the intensity of development allowed.

The Nagawicka Lake watershed contains a dozen local units of governments with different regulatory authorities that influence Lake protection including Waukesha and Washington Counties, the City of Delafield, the Villages of Chenequa, Hartland, Merton, Nashotah, Richfield, and Sussex, and the Towns of Merton, Lisbon, and Delafield (see Map 2.1 and Table 2.8). Waukesha County has zoning authority for much of the watershed. This is advantageous because the general zoning ordinance for Waukesha County specifically states that environmental corridors in the Environmental Corridor District are to be protected and maintained. The fact that environmental corridors are accounted for in zoning decisions means that many critical and/or sensitive areas within the Nagawicka Lake watershed are well protected (see Map 2.20).

In addition to general zoning, shoreland zoning, construction site erosion control, and stormwater management ordinances also play a key role in protecting the resources within the watershed. Shoreland zoning, for example, which is primarily administered by Waukesha and Washington Counties, follows State standards to establish building setbacks around navigable waters.[200] Additionally, stormwater management and construction erosion control ordinances help minimize negative impacts of development on water resources, such as water pollution and flooding.

Several important recommendations under this plan relate to municipal or county ordinance enforcement (e.g., shoreline setbacks, zoning, construction site erosion control, drainage, and boating). Local governments often have limited resources at their disposal to assure rules are respected and properly applied. Consequently, the following recommendations are aimed at local citizens, Lake users, and management groups, and are made to enhance the ability of the responsible entities to successfully monitor and enforce existing regulations:

- **Recommendation 8.1: Maintain and enhance relationships with County and municipal zoning administrators and law enforcement officers**
  This helps build open relationships with responsible entities and facilitates efficient communication and collaboration whenever needed. This should be assigned a high priority.

- **Recommendation 8.2: Keep abreast of activities within the watershed that can affect the Lake**
  Certain activities (e.g., construction, filling, erosion) could potentially affect the Lake. Maintaining good records (e.g., notes, photographs) and judiciously notifying relevant regulatory entities of problems when deemed appropriate is recommended as a high priority.

[200] *The 2015-2017 State Budget (Act 55) changed State law relative to shoreland zoning. Under Act 55 a shoreland zoning ordinance may not regulate a matter more restrictively than it is regulated by a State shoreland-zoning standard unless the matter is not regulated by a standard in Chapter NR 115, "Wisconsin's Shoreland Protection Program," of the* Wisconsin Administrative Code*. (Examples of unregulated matters may involve wetland setbacks, bluff setbacks, development density, and stormwater standards.) In addition, under Act 55, a local shoreland zoning ordinance may not require establishment or expansion of a vegetative buffer on already developed land and may not establish standards for impervious surfaces unless those standards consider a surface to be pervious if its runoff is treated or is discharged to an internally drained pervious area.*

Figure 3.8
SEWRPC Environmental Corridor Synopsis

SEWRPC embraced and applied the environmental corridor concept developed by Philip Lewis (Professor Emeritus of Landscape Architecture at the University of Wisconsin-Madison) with the publication of its first regional land use plan in 1966. Since then, SEWRPC has refined and detailed the mapping of environmental corridors, enabling the corridors to be incorporated directly into regional, county, and community plans and to be reflected in regulatory measures. The preservation of environmental corridors remains one of the most important recommendations of the regional plan. Corridor preservation has now been embraced by numerous county and local units of government as well as by State and Federal agencies. The environmental corridor concept conceived by Lewis has become an important part of the planning and development culture in southeastern Wisconsin.

Environmental corridors are divided into the following three categories.

- Primary environmental corridors contain concentrations of our most significant natural resources. They are at least 400 acres in size, at least two miles long, and at least 200 feet wide.

- Secondary environmental corridors contain significant but smaller concentrations of natural resources. They are at least 100 acres in size and one mile long, unless they link primary corridors.

- Isolated natural resource areas contain significant remaining resources that are not connected to environmental corridors. They are at least five acres in size and at least 200 feet wide.

Key Features of Environmental Corridors

- Lakes, rivers, and streams
- Undeveloped shorelands and floodlands
- Wetlands
- Woodlands
- Prairie remnants
- Wildlife habitat
- Rugged terrain and steep slopes
- Unique landforms or geological formations
- Unfarmed poorly drained and organic soils
- Existing outdoor recreation sites
- Potential outdoor recreation sites
- Significant open spaces
- Historical sites and structures
- Outstanding scenic areas and vistas

Source: SEWRPC

- **Recommendation 8.3: Educate watershed residents about relevant ordinances. Update ordinances as necessary to face evolving use problems and threats**
  This helps assure that residents know why rules are important, that permits are required for almost all significant grading or construction, and that such permits offer opportunity to regulate activities that could harm the Lake. This should be considered a high priority.

State Regulations

The State Legislature required the WDNR to develop performance standards for controlling nonpoint source pollution from agricultural and nonagricultural land and from transportation facilities.[201] The performance standards, which are set forth in Chapter NR 151, "Runoff Management," of the *Wisconsin Administrative Code*, set forth requirements for best management practices. Similar regulations cover construction sites, wetland protective areas, and buffer standards.

Water quality objectives are presented in *Wisconsin Administrative Code* Chapter NR 102, "Water Quality Standards for Wisconsin Surface Waters." These rules set water quality standards that promote healthy aquatic ecosystems and public enjoyment of waterbodies. Some of the standards set in this rule applicable to Nagawicka Lake include the following:

- Dissolved oxygen concentrations greater than or equal to 5.0 mg/L
- pH between 6.0 and 9.0 SU
- Fecal coliform geometric mean less than or equal to 200 colonies per 100 milliliters, single sample maximum less than or equal to 400 colonies per 100 milliliters
- Total phosphorus concentration (summer epilimnion) of 20 μg/L (or 0.020 mg/L)
- Chloride acute toxicity concentration of 757 mg/L, chronic toxicity concentration of 395 mg/L

Chapter NR 102 further stipulates maximum temperatures for each month, with the highest standards applying to July and August when the following maxima apply: ambient water temperature of less than or equal to 77°F, sublethal water temperature of less than or equal to 80°F for one week or less, and acute water temperature of less than or equal to 87°F for one day or less.

The regulations described above play a crucial part in maintaining the health of Nagawicka Lake and the resources within its watershed. However, even though developers, residents, and Lake users are legally obligated to adhere to the ordinances, limited resources within enforcement bodies at State, County, and municipal levels can sometimes make the task of ensuring compliance difficult.

Proactive Management Efforts

In addition to continued and enhanced regulatory enforcement, a number of recommendations seek to proactively improve conditions within the Lake and its watershed through voluntary management efforts. However, several challenges can limit the ability of Lake residents and the LWC to engage in certain management efforts recommended in this plan. Some of these challenges include:

[201] *The State performance standards are set forth in the Chapter NR 151, "Runoff Management," of the* Wisconsin Administrative Code*. Additional code chapters that are related to the State nonpoint source pollution control program include: Chapter NR 152, "Model Ordinances for Construction Site Erosion Control and Storm Water Management" (This Chapter will be revised in response to the 2013 Wisconsin Act 20 as noted in WDNR Guidance #3800-2014-3, "Implementation of 2013 Wisconsin Act 20 for Construction Site Erosion Control and Stormwater Management," October 2014.); Chapter NR 153, "Runoff Management Grant Program;" Chapter NR 154, "Best Management Practices, Technical Standards and Cost-Share Conditions;" Chapter NR 155, "Urban Nonpoint Source Water Pollution Abatement and Storm Water Management Grant Program;" and Chapter ATCP 50, "Soil and Water Resource Management." Those chapters of the* Wisconsin Administrative Code *became effective in October 2002. Chapter NR 120, "Priority Watershed and Priority Lake Program," and Chapter NR 243, "Animal Feeding Operations," were repealed and recreated in October 2002.*

- **Lack of adequate funding.** Concerns have been expressed regarding the costs associated with management efforts recommended under this plan. Costs may be partially offset by grants in some instances. Adopting an adaptive management approach with wastewater treatment facilities within the Bark River watershed may also provide cost-sharing opportunities to implement best management practices.

- **Institutional cooperation and capacity.** Institutional capacity refers to assets available through agencies, universities, schools, service groups, and NGOs that can be used to implement projects. These assets can be defined in terms of knowledge, staff, equipment, and other resources.

  As stated on their website, the LWC "studies all problems and issues relating to Nagawicka Lake and the Bark River within the city limits." One of the primary missions of the LWC is directing activities associated with aquatic plant management and dredging. The LWC includes representation from both the City of Delafield and Village of Nashotah, and, hence, has the capacity to represent all riparian property owners. However, the LWC does not include specific representation from the Waukesha County Parks and Land Use Department, who owns and operates Naga-Waukee Park. This park is one of the largest riparian parcels on the Lake, is the sole public access point, and is vitally important to a large segment of Lake users.

- **Inadequate numbers of volunteers.** To increase the advocacy, learning opportunities, and volunteer numbers for labor intensive or broad-based projects (e.g., hand pulling wetland invasive species monitoring), it is desirable to reach a broad stakeholder group and involve members of the LWC, Lake users, the general public, organizations, and agencies with an interest in the water resources of the Nagawicka Lake watershed. The planning process for Nagawicka Lake reveals that many stakeholders have strong connections to the Lake. However, participants in the planning process were almost entirely composed of lakeshore or near-lakeshore residents. To increase the advocacy and volunteer base for projects, it will be necessary to reach a group that extends beyond lakeshore residents. For example, a group could be formed that focuses on the Bark River.

Since lack of funding, institutional capacity, and outreach commonly hinder local citizens and management groups from effectively executing Lake management projects, the following suggestions are offered to enhance project execution:

➤ **Recommendation 8.4: Apply for grants to help implement plan-recommended programs**
This should be considered a high priority. This process requires coordination, collaboration, creativity, and investment of stakeholder time to be effective. Table 3.2 provides a list of WDNR-sponsored grant application opportunities that can potentially be used to implement plan recommendations. Examples of other possible funding sources include charitable institutions, businesses, a large number of Federal agency grants, and in-kind donations. It is often desirable to collaborate with project partners to increase project appeal to potential funding sources; adopting an adaptive management plan could be extremely beneficial in this regard.

Individual lakeshore property owners may also be eligible for funding through the WDNR Healthy Lakes & Rivers Program, but the LWC must apply on the property owners' behalf. The LWC, through its affiliation with the City of Delafield and the Village of Nashotah, is a qualified sponsor and the State of Wisconsin's Healthy Lakes & Rivers Implementation Plan has been fully integrated into the comprehensive planning goals and recommendations of this plan. At least one Healthy Lakes & Rivers project, a native planting along the northern shoreline, has already been implemented. In addition, the LWC is eligible for a Board of Commissioners of Public Lands loan program to implement projects for the Lake.

➤ **Recommendation 8.5: Broaden Lake Welfare Committee representation**
Include a representative of the Waukesha County Land Use and Parks Department as a regular member of the LWC. This will help allow the needs of desires of a large group of potentially unrepresented Lake users to be heard and should be considered a high priority.

- **Recommendation 8.6: Encourage Lake users and residents to actively participate in future management efforts**
  Not only does this effort help assure community support, but also supplements the donor and volunteer pool currently working toward improving the Lake. This should be considered a medium priority. Broad-based resident engagement on future efforts benefits the Lake, but also benefits the value of their properties.

- **Recommendation 8.7: Encourage key players to attend meetings, conferences, and/or training programs to build lake management knowledge and to enhance institutional knowledge and capacity**
  Recognizing the limited financial resources and time normally available for such activities, this element is assigned a medium priority. Some examples of capacity-building events are Wisconsin Water Week (which targets local lake managers) and the "Lake Leaders" training program (which teaches the basics of lake management and provides ongoing resources to lake managers). Both of these are hosted by the University of Wisconsin-Extension. Additionally, in-person and on-line courses, workshops, training, regional summits, and general meetings can also be of value. Attending these events should include follow-up documents/meetings to help assure that the lessons learned are communicated to the larger Lake group.

- **Recommendation 8.8: Continue to reinforce stakeholder inclusivity and transparency with respect to all Lake management activities**
  If stakeholders do not fully understand the aims and goals of a project, or if they do not trust the process, excess energy can be devoted to conflict, a result that benefits no one. For this reason, this element is assigned a high priority. These efforts should be implemented through public meetings, social media, newsletters, emails, and any other mechanism that helps disperse and gather a full suite of information and builds consensus. In this way, all data and viewpoints can be identified and considered, and conflicts can be discussed, addressed, and mitigated before finalizing plans and implementing projects.

- **Recommendation 8.9: Foster and monitor efforts to communicate concerns, goals, actions, and achievements to future Lake managers**
  Institutional knowledge is a powerful tool that should be preserved whenever possible; therefore, this recommendation is assigned a high priority. Open communication helps further increase capacity of Lake management entities. This may take the form of annual meetings, internet websites, social media, newsletters, emails, reports, and any number of other means that help compile and report actions, plans, successes, and lessons learned. Institutional knowledge can be preserved through the minutes of lake organization meetings; therefore, these records should be kept indefinitely.

- **Recommendation 8.10: Develop an action plan**
  Advancing any lake protection plan requires the implementing agency to have competent technical guidance, management skill, and political savvy. To be truly effective, plan implementation must identify tangible goals and quantifiable metrics to measure progress and relative success. Developing an action plan with timelines, goals, and identified responsible parties is a significant step toward plan implementation. Target metrics can help the implementing agencies and funders gauge progress over time and can help motivate participants, ensuring that the plan is carried through in the long term. Additionally, an action plan can help ensure that all responsible parties are held accountable for their portions of the plan's implementation. When developing an action plan, it is important to know what on-the-ground implementation involves. Developing and using an action plan should be assigned a high priority.

As a final note, to promote plan implementation, the LWC and the City of Delafield should actively reach out and educate Lake residents, users, watershed municipalities, the DelaHart wastewater treatment plant, and NGOs regarding the content and goals of this plan. A campaign to communicate the most important information should therefore be given high priority. This outreach/education effort must include a message that recognizes and stresses that this plan is a dynamic document that uses the best available information, goals, and situation at a set point in time. As such, the plan should continually evolve to incorporate new ideas and new data.

3.10 SUMMARY AND CONCLUSIONS

The future will bring change to Nagawicka Lake and its watershed. Projections suggest that some of the agricultural land use in the watershed of today will give way to urban residential land use. It is critical that proactive measures be pursued to lay the groundwork for effectively dealing with and benefiting from future change. Working relationships with appropriate local, County, and State entities need to be nurtured now and in the future. These relationships ultimately will help protect critical natural areas in the watershed during development, will help initiate actions (such as residential street leaf litter pickup and disposal), and will help instill attitudes among current and future residents that will foster cooperation and coordination of effort on many levels.

To help implement plan recommendations, Table 3.1 summarizes all recommendations and their priority level. Additionally, Appendices D and E, in combination with the aquatic plant management recommendations (see Figures 3.3 through 3.6), indicate where recommendations should be implemented. These guides will provide current and future Nagawicka Lake managers with a visual overview of where to target management efforts.

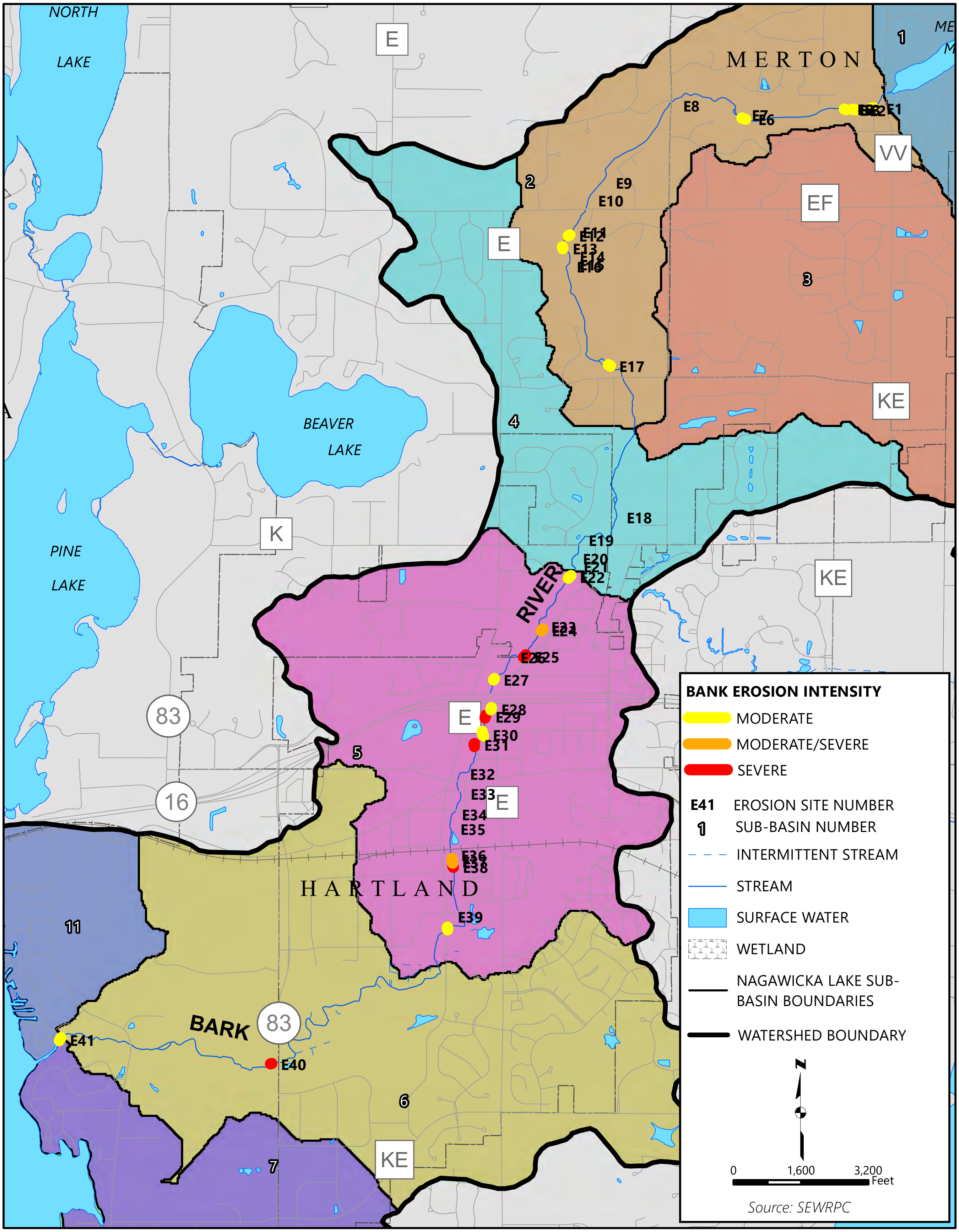
As stated in the introduction, this chapter is intended to stimulate ideas and action. Therefore, these recommendations should provide a starting point for addressing the issues identified in Nagawicka Lake and its watershed. Successfully implementing this plan requires vigilance, cooperation, and enthusiasm, not only from local management groups, but also from State and regional agencies, Waukesha and Washington Counties, municipalities, and Lake residents, Lake users, and the general public. Implementation of the recommended measures will provide the water quality and habitat protection necessary to maintain or establish conditions in the watershed that are suitable for maintaining and improving the natural beauty and ambience of Nagawicka Lake and its ecosystem. This, in turn, benefits the Region's human population today and in the future.

APPENDICES

APPENDIX A

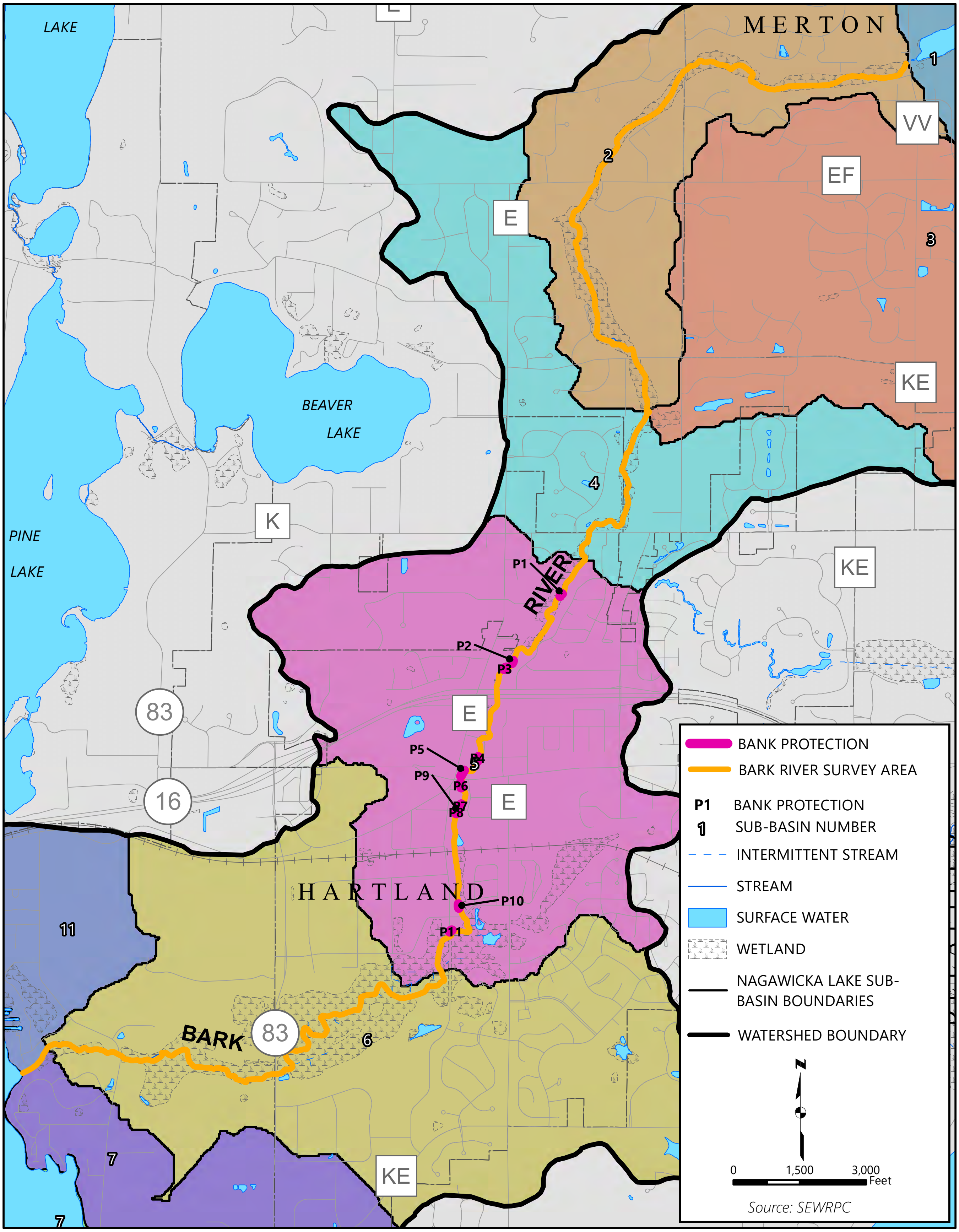
BARK RIVER SURVEY DATA

Map A.1
Areas of Bank Erosion Found During the September 2016 Bark River Survey

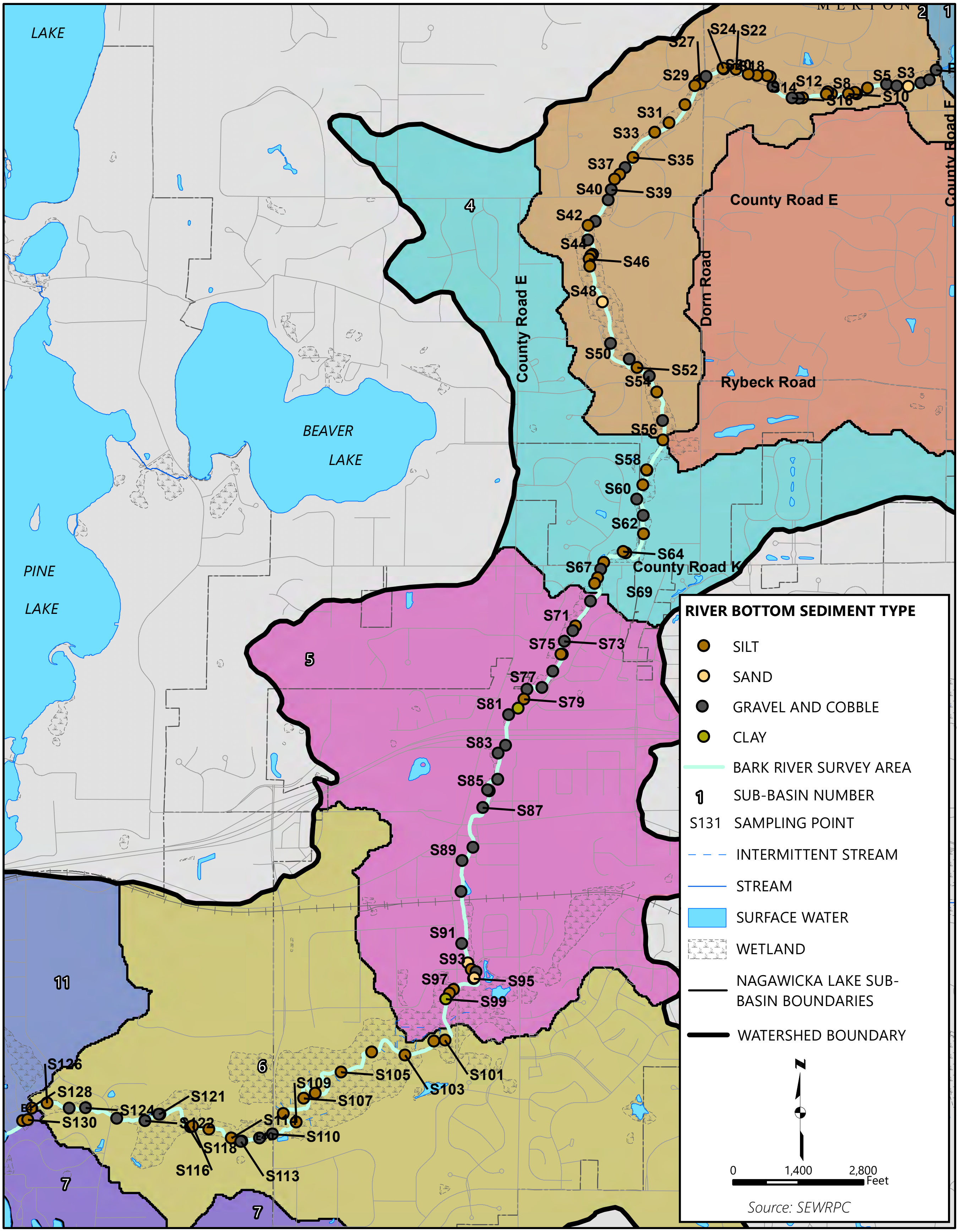


Source: SEWRPC

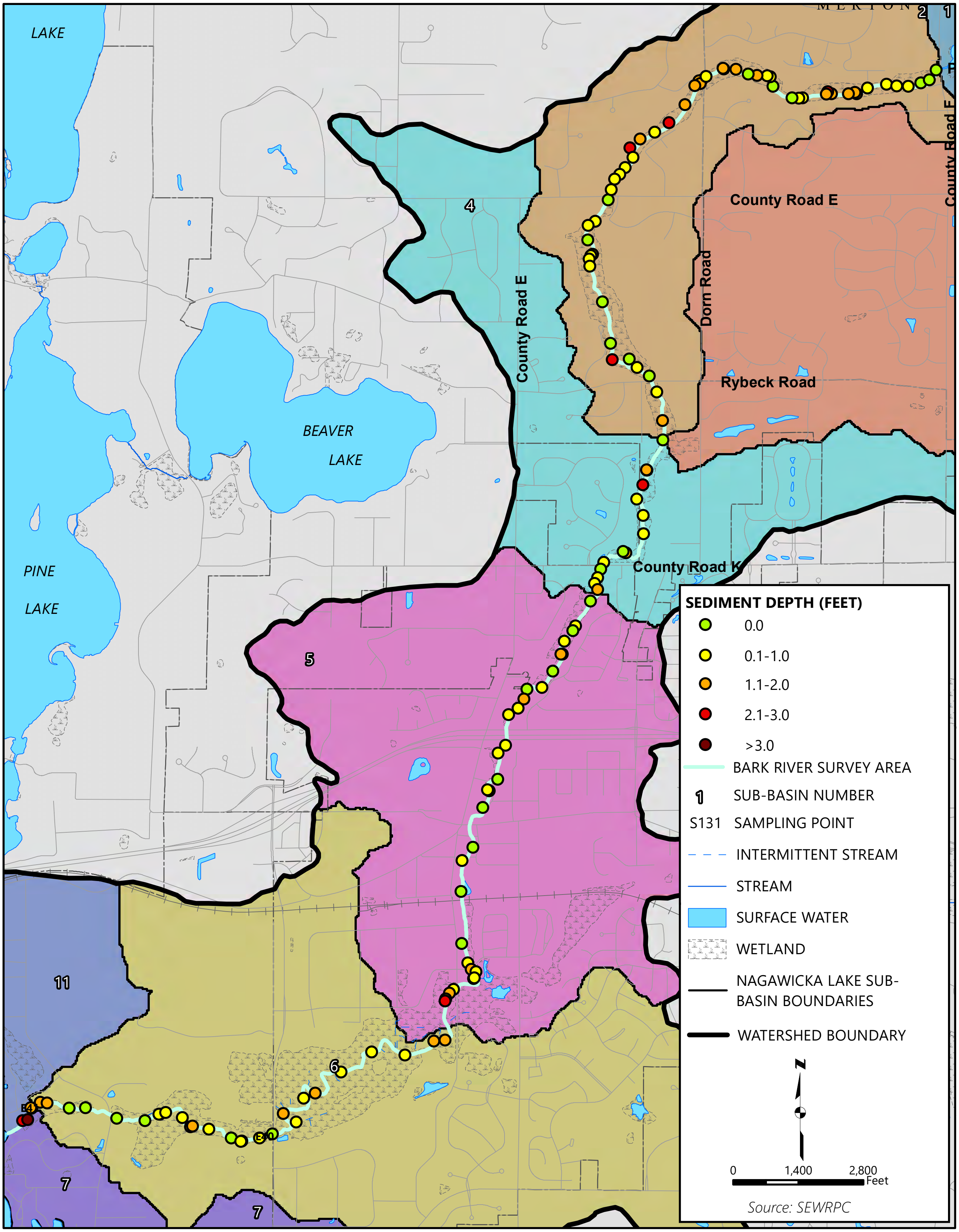
Map A.2
Bank Protection Located During Bark River Survey: September 2016



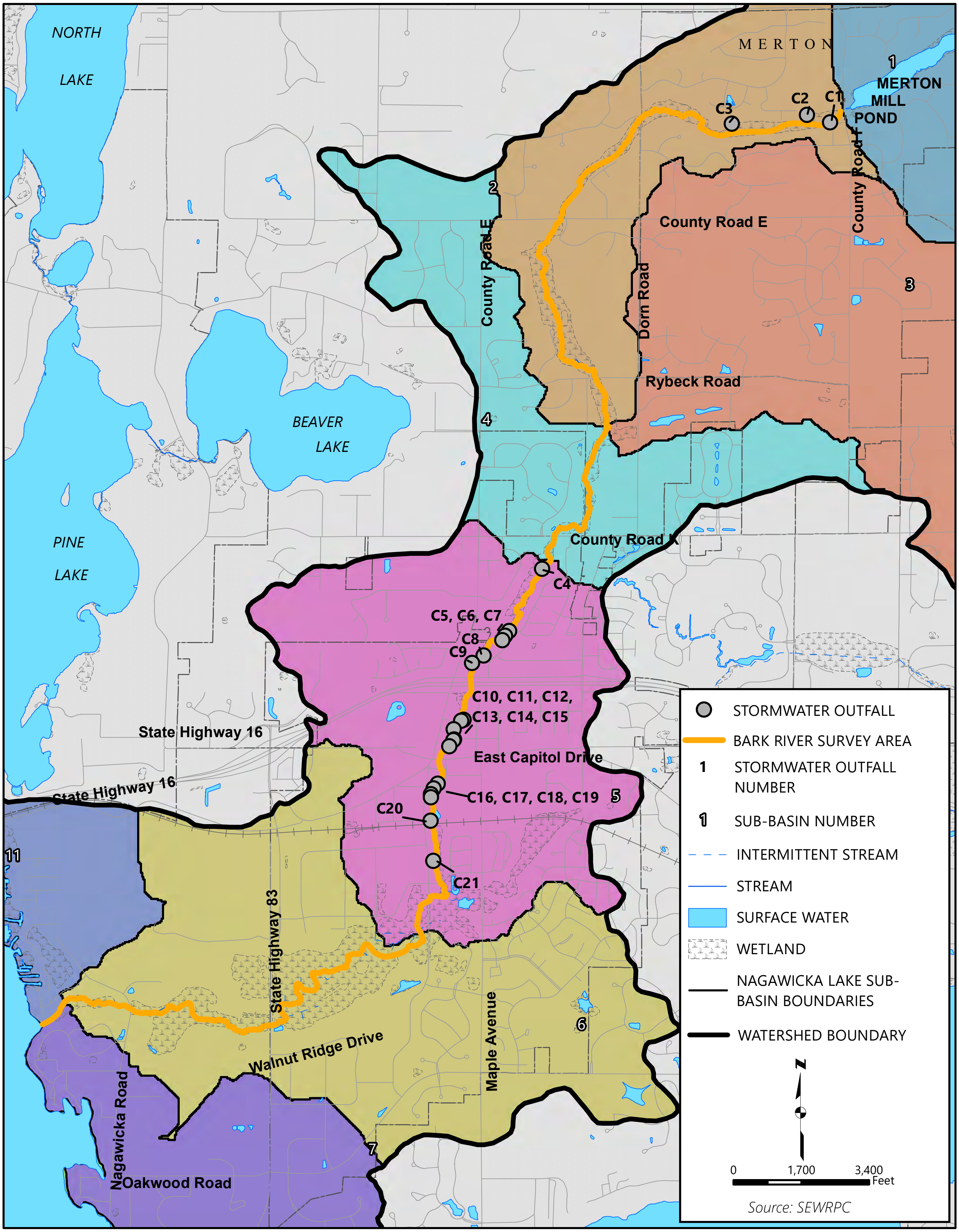
Map A.3
Bark River Bottom Sediment Types: September 2016



Map A.4
Bark River Bottom Sediment Depth: September 2016



Map A.5
Stormwater Outfalls Along the Bark River: September 2016



Map A.6
Channel Obstructions Along Bark River: September 2016

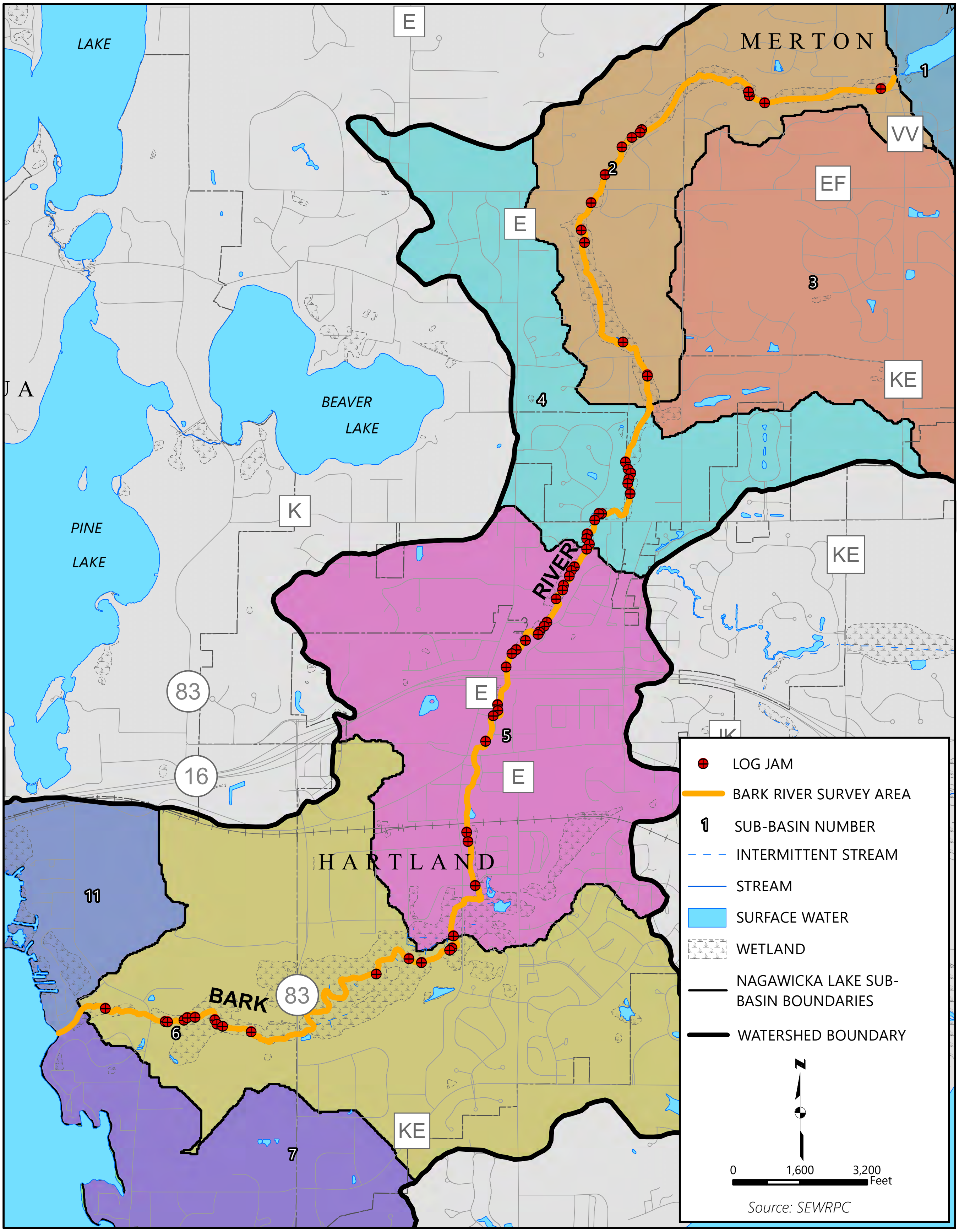


Table A.1
Potential Actively Eroding Sites Located During Bark River Survey: September 2016

Map Label	Bank	Minimum Height (feet)	Maximum Height (feet)	Depth of Undercut (feet)	Notes	Photo Description	Length (feet)
E1	Left	1.4	1.7	0.4	0.1 to 0.7 ft range undercutting on bank	Cobble and roots in loam	71.34
E2	Left	1.0	2.0	0.0	Natural erosion exposed roots and overhanging vegetation	Natural erosion and undercutting no photo though	86.66
E3	Left	0.5	0.9	1.0	Some type of protective material failing	Undercutting and looks like maybe attempt was made to fix before	80.03
E4	Both	0.5	1.5	0.2		Exposed tree roots and cobble	41.38
E5	Left	0.5	2.0	0.3		Very flat area of erosion	61.02
E6	Left	1.0	1.5	0.3	Undercut only in small spots	Natural erosion area	68.94
E7	Right	0.5	1.5	0.5		Very mild erosion	34.08
E8	Left	2.5	7.0	0.0		Bank next to roadway could have more vegetation for buffering	61.38
E9	Left	0.5	2.5	0.3		Light erosion and rip rap for protection	158.42
E10	Right	1.2	2.1	0.6		Mild undercutting in clay and loam	52.27
E11	Left	0.8	1.8	0.4	0.2 to 2.6 ft undercut range	mild erosion and exposed tree roots into loam	102.02
E12	Right	1.0	1.5	0.6		Mild erosion and undercutting	60.24
E13	Left	3.0	5.0	0.0		Most severe erosion but for short distance	39.62
E14	Right	0.5	3.5	0.6		Concentrated area of erosion	68.70
E15	Both	0.5	1.5	0.2		Consistent with exposed roots and mild undercut	95.88
E16	Left	1.4	0.0	0.0		Short area with exposed roots	50.52
E17	Right	1.0	2.0	0.0	Exposed roots no undercutting	Very mild with some root exposure	55.13
E18	Left	0.5	3.0	0.0		Concentrated area of root exposure	166.40
E19	Left	2.0	3.0	0.0		No picture	64.87
E20	Right	2.0	3.0	0.2		Very flat area of erosion	73.42
E21	Right	1.5	2.0	0.2		Eroded area with root exposure and falling tree	123.96
E22	Right	5.0	8.0	0.0		Tall scoured area but covered with vegetation and moss	108.40
E23	Left	0.0	0.0	0.2	Light erosion and undercutting	marsh area	115.29
E24	Left	0.0	0.0	0.2	Mild erosion and undercutting	Natural erosion in marsh area	86.52
E25	Right	0.5	1.0	0.6		Mild erosion	31.36
E26	Left	0.8	2.4	0.0		Very short and no photo was taken	27.70
E27	Left	1.5	3.0	0.9		Very mild erosion with vegetation	93.29
E28	Left	1.4	1.9	0.1		Scouring and lots of tree roots	83.29
E29	Left	0.5	2.0	0.5	Exposed roots	Mostly mild with area of clear undercutting and root exposure	91.96
E30	Left	0.0	3.5	0.4		Erosion and undercutting under ferns	32.43

Table continued on next page.

Table A.1 (Continued)

Map Label	Bank	Minimum Height (feet)	Maximum Height (feet)	Depth of Undercut (feet)	Notes	Photo Description	Length (feet)
E31	Both	0.5	1.6	0.7	Undercut range 0.2-1.8 ft	Mild undercutting in loam	135.51
E32	Right	0.5	3.5	4.5		Severe undercutting and exposed roots	22.13
E33	Right	0.7	1.2	0.8		Mild undercutting into clay and loam	105.52
E34	Right	1.0	1.2	0.6		Mild undercutting in clay and loam	29.51
E35	Left	1.0	1.8	0.4	0.2 to 0.8 ft undercut		86.20
E36	Left	0.0	0.0	1.2		Natural erosion into muck	3.70
E37	Left	0.5	1.0	0.2		Mild erosion and undercutting	44.70
E38	Right	0.5	1.5	0.5		Mild erosion and undercutting	56.36
E39	Right	0.5	1.0	0.0		Area of concentrated erosion and exposed roots channelized	73.81
E40	Both	0.5	1.0	0.2		Mostly mild with a concentrated spot of more severe erosion	136.05
E41	Left	1.0	1.8	0.3		Small area of mild erosion	26.70

Figure A.1
Potential Actively Eroding Sites of Concern: September 2016

Dimensions
Average Height: 1.6 feet
Length: 71 feet

Dimensions
Average Height: 1.1 feet
Length: 135 feet

Dimensions
Average Height: 1.7 feet
Length: 52 feet

Figure A.1 (Continued)

Dimensions
Average Height: 1.3 feet
Length: 100 feet

Dimensions
Average Height: 1.3 feet
Length: 60 feet

Dimensions
Average Height: 4.0 feet
Length: 40 feet

Figure A.1 (Continued)

Dimensions
Average Height: 2.0 feet
Length: 68 feet

Dimensions
Average Height: 1.0 feet
Length: 95 feet

Dimensions
Average Height: 2.5 feet
Length: 73 feet

Dimensions
Average Height: 1.7 feet
Length: 83 feet

Figure A.1 (Continued)

Dimensions
Average Height: 0.7 feet
Length: 50 feet

Dimensions
Average Height: 1.5 feet
Length: 55 feet

Dimensions
Average Height: 1.3 feet
Length: 90 feet

Dimensions
Average Height: 1.8 feet
Length: 55 feet

Figure A.1 (Continued)

Dimensions
Average Height: 0.7 feet
Length: 80 feet

Dimensions
Average Height: 1.8 feet
Length: 120 feet

Figure A.1 (Continued)

Dimensions
Average Height: 1.8 feet
Length: 32 feet

A photograph was not taken during the survey.

Dimensions
Average Height: 2.5 feet
Length: 65 feet

E39

A photograph was not taken during the survey.

Dimensions
Average Height: 1.5 feet
Length: 85 feet

E41

Dimensions
Average Height: 2.0 feet
Length: 22 feet

Table A.2
Shoreline Protection Located During Bark River Survey: September 2016

Map Label	Bank	Type	Minimum Height (feet)	Maximum Height (feet)	Average Height (feet)	Notes	Length	Summary
P1	Right	Restoration Project	3.0	3.0	3.0		69.96	Bio
P2	Right	Restoration Project	2.1	2.1	2.1	Biologs	66.58	Bio
P3	Right	Restoration Project	2.3	2.4	2.3	Biologs or bags	63.12	Bio
P4	Right	Other	0.5	2.5	1.5	Stone failing falling apart in some spots	118.76	Rip rap
P5	Left	Rip Rap	0.5	1.5	1.0		153.61	Wall
P6	Left	Other	2.0	4.0	3.0	Stone wall	112.99	Wall
P7	Right	Rip Rap	0.4	1.5	1.0		72.98	Rip rap
P8	Left	Other	5.0	5.0	5.0	Stone wall failing in spots	30.55	Wall
P9	Right	Restoration Project	3.0	4.0	3.5	Biologs	80.35	Bio
P10	Both	Rip Rap	1.0	2.5	1.7	Large boulders	94.81	Rip rap
P11	Left	WPA Wall	5.5	5.5	5.5		71.51	Wall

Figure A.2
Shoreline Protection Site Photographs: September 2016

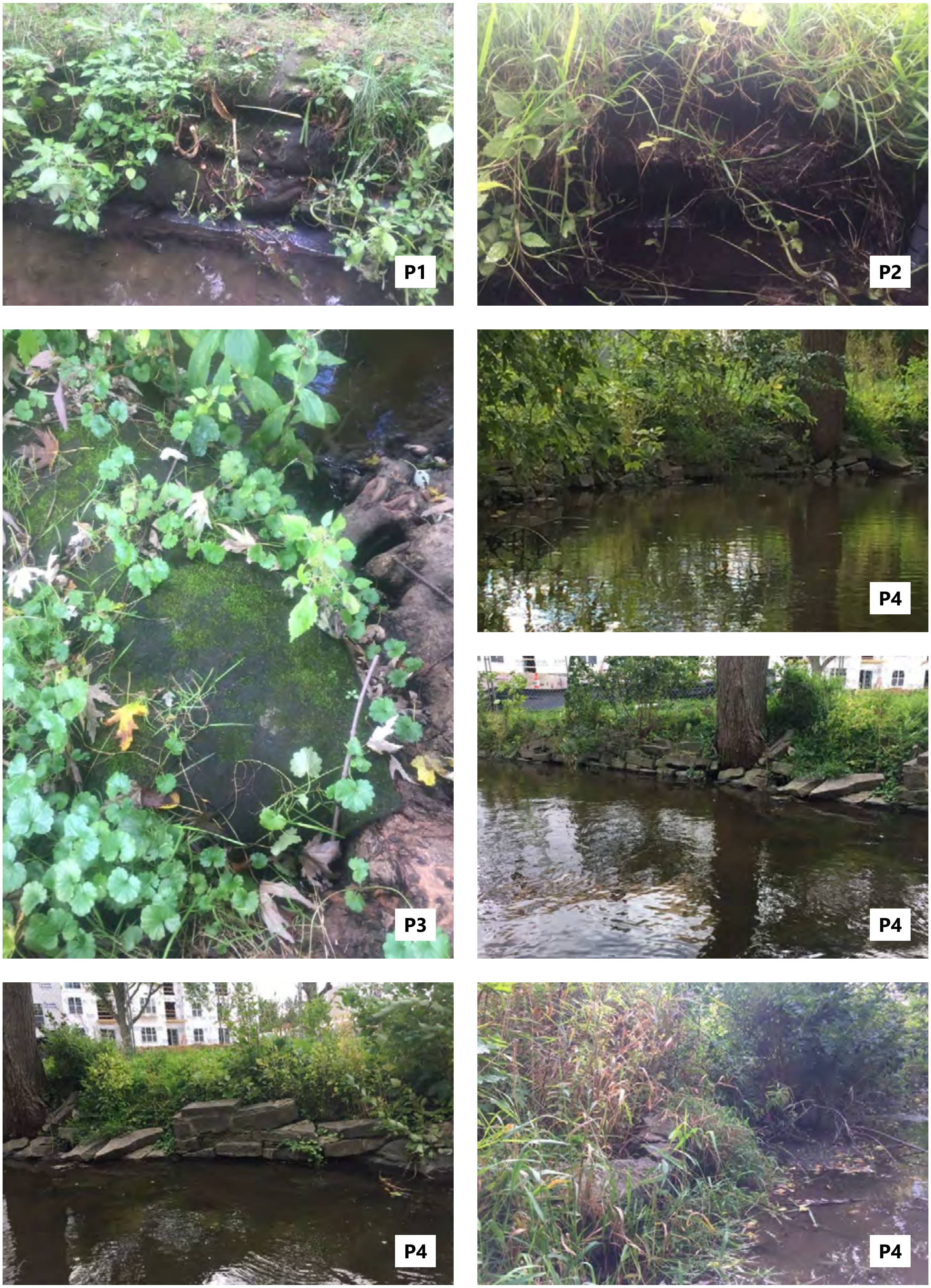


Figure A.2 (Continued)

Figure A.2 (Continued)

Table A.3
Bark River Sediment Survey Points: September 2016

Map Label	Water Depth (feet)	Water Plus Sediment Depth (feet)	Sediment Depth (feet)	Notes
S1	0.7	0.7	0.0	Gravel
S2	0.6	0.6	0.0	Gravel shallow riffle
S3	2.6	2.6	0.0	Gravel and cobble
S4	0.7	1.0	0.3	Sand and gravel
S5	1.2	1.4	0.2	Gravel
S6	1.4	1.5	0.1	Gravel and fist to head size cobble
S7	1.1	1.3	0.2	Silt over gravel sparse coontail around
S8	1.1	2.3	1.2	Silt buildup
S9	0.9	2.1	1.2	Sediment build up on right bank
S10	1.0	2.1	1.1	Sediment buildup across river
S11	1.1	2.7	1.6	Sediment buildup
S12	1.0	3.7	2.7	Silt deposit across river
S13	1.8	2.9	1.1	Silt deposit lessens
S14	1.0	1.2	0.2	Silt over clay first break from deep deposits upstream
S15	1.4	1.5	0.1	Gravel
S16	0.5	0.5	0.0	Gravel rock riffle
S17	1.1	1.1	0.0	Gravel and large boulders
S18	1.3	1.6	0.3	Silt over gravel
S19	0.9	1.7	0.8	Silt buildup
S20	1.1	2.7	1.6	Silt buildup across river
S21	2.4	2.4	0.0	Silt over head size rock
S22	1.7	2.8	1.1	Silt deposit
S23	1.5	1.6	0.1	Silt over gravel nice plant beds
S24	1.0	2.9	1.9	Silt over rock
S25	1.2	1.3	0.1	Gravel and moderate aquatic plant beds
S26	1.8	2.0	0.2	Gravel and cobble
S27	0.6	1.7	1.1	Silt deposits along right bank
S28	1.1	2.3	1.2	Silt deposit continues
S29	0.7	2.3	1.6	Silt very thick
S30	0.6	1.9	1.3	Silt deposits
S31	1.4	3.8	2.4	Silt deposit continues
S32	2.8	2.9	0.1	Silt over gravel
S33	0.8	2.6	1.8	
S34	0.7	3.0	2.3	
S35	2.7	2.9	0.2	Silt over gravel large boulders 1 to 2 ft across
S36	2.2	2.3	0.1	Gravel
S37	1.3	1.7	0.4	Silt over rock
S38	2.3	2.9	0.6	Silt over rock
S39	2.5	2.6	0.1	Gravel and rock
S40	1.1	1.1	0.0	Gravel and cobble
S41	1.5	1.6	0.1	Gravel cobble
S42	0.8	1.6	0.8	Silt on left bank
S43	1.3	1.3	0.0	Gravel and cobble
S44	1.8	2.3	0.5	Silt and gravel
S45	0.9	1.8	0.9	Silt
S46	2.9	3.1	0.2	Silt and gravel some larger rocks
S47	1.7	2.6	0.9	Silt
S48	1.2	1.2	0.0	Sandy gravel cobble
S49	1.0	1.0	0.0	Gravel cobble sand
S50	0.7	3.4	2.7	Big pool area with lily pads and coontail silt
S51	1.3	1.3	0.0	Gravel and foot wide rocks
S52	1.0	1.1	0.1	Silt gravel cobble

Table continued on next page.

Table A.3 (Continued)

Map Label	Water Depth (feet)	Water Plus Sediment Depth (feet)	Sediment Depth (feet)	Notes
S53	1.8	1.8	0.0	Gravel cobble
S54	1.5	1.8	0.3	Silt over gravel
S55	1.6	2.9	1.3	Firm not easy to push in
S56	1.2	1.2	0.0	Silt over gravel and large stones
S57	1.5	2.4	0.9	Silt
S58	1.0	2.6	1.6	Silt deposit along left bank
S59	1.0	3.3	2.3	Wider area more silt deposited very calm current
S60	2.0	2.1	0.1	Gravel
S61	1.5	1.6	0.1	Fist to head size cobble
S62	1.3	2.1	0.8	Silt
S63	1.3	2.4	1.1	Silt
S64	2.9	2.9	0.0	Silt over rock
S65	1.1	1.3	0.2	Silt over rock
S66	0.7	0.7	0.0	Gravel and cobble
S67	1.8	2.1	0.3	Silt over gravel
S68	0.4	1.1	0.7	Silt deposit
S69	0.6	2.2	1.6	
S70	1.3	1.3	0.0	Gravel and cobble
S71	1.6	1.7	0.1	Silt and gravel
S72	1.5	1.5	0.0	Gravel and head size cobble
S73	2.4	2.5	0.1	Gravel and cobble
S74	1.8	1.9	0.1	Silt over gravel
S75	0.6	1.8	1.2	Silt deposit along right bank
S76	1.4	1.4	0.0	Cobble gravel
S77	1.4	1.5	0.1	Gravel and cobble
S78	1.1	1.1	0.0	Gravel and cobble
S79	1.1	2.2	1.1	Sediment deposit along right bank
S80	2.8	3.1	0.3	Clay
S81	1.7	1.8	0.1	Gravel and sand
S82	0.8	0.9	0.1	Gravel and cobble
S83	1.9	2.5	0.6	Gravel
S84	2.6	2.6	0.0	Gravel
S85	0.7	1.5	0.8	Silt deposit along bank
S86	2.0	2.1	0.1	Gravel
S87	2.2	2.2	0.0	Gravel
S88	1.0	1.0	0.0	Gravel rock rapid
S89	1.4	1.5	0.1	Gravel and rocks
S90	1.6	1.6	0.0	Gravel
S91	1.0	1.0	0.0	Gravel
S92	2.2	2.3	0.1	Sand and gravel
S93	0.3	2.0	1.7	Silt and leaves LOTS of detritus
S94	1.5	1.8	0.3	Gravel
S95	1.0	1.8	0.8	Silt
S96	1.4	1.7	0.3	Sand and gravel
S97	2.5	2.8	0.3	Silt over gravel
S98	1.2	2.3	1.1	Silt over gravel
S99	4.0	4.2	0.2	Solid bottom felt clay like
S100	0.8	3.4	2.6	
S101	3.6	5.0	1.4	Greater than 5 silt and detritus
S102	1.2	2.4	1.2	Silt and a little detritus
S103	2.0	2.6	0.6	Silt
S104	2.7	3.1	0.4	Silt over clay
S105	2.9	3.2	0.3	Silt
S106	1.6	2.7	1.1	Silt over hard bottom

Table continued on next page.

Table A.3 (Continued)

Map Label	Water Depth (feet)	Water Plus Sediment Depth (feet)	Sediment Depth (feet)	Notes
S107	2.3	3.1	0.8	Silt over hard bottom
S108	1.8	3.3	1.5	Silt
S109	1.6	2.6	1.0	Silt
S110	1.1	1.1	0.0	Gravel and cobble
S111	1.6	1.9	0.3	Heavily cobbled fist size to head size
S112	1.0	3.7	2.7	Ridge of silt deposit
S113	2.7	3.0	0.3	Gravel bottom
S114	1.5	1.5	0.0	Silt gravel cobble
S115	2.2	3.2	1.0	Silt
S116	1.2	2.3	1.1	Silt
S117	1.2	1.7	0.5	Deposits of sediment along banks
S118	2.5	3.5	1.0	
S119	3.8	4.6	0.8	
S120	0.6	1.6	1.0	Silt deposit
S121	2.2	2.4	0.2	Gravel and silt no cobble
S122	1.8	1.8	0.0	Cobble
S123	1.0	1.0	0.0	Gravel and cobble
S124	1.0	1.0	0.0	Gravel and cobble
S125	1.0	1.0	0.0	Rocks cobble and gravel
S126	1.5	3.3	1.8	Silty
S127	1.6	3.0	1.4	
S128	2.1	3.2	1.1	
S129	0.4	2.7	2.3	Mucky silt
S130	0.9	4.0	3.1	Ridge of sediment toward left bank
S131	1.1	3.6	2.5	Soft silt

Table A.4
Stormwater Outfalls Located During Bark River Survey: September 2016

Map Label (pond to lake)	Bank	Type	Width	Height	Condition	Street Nearby
C1	Right	Plastic	0.5	0.5	Good	Waukesha VV and Mill Street
C2	Left	Cement	3.2	3.2	Good	Fishers Landing and Spinners Pass
C3	Right	Cement	3.0	1.8	Good	Rae Drive and Hawthorne Lane near Centennial Park
C4	Right	Cement	3.7	3.7	Good	Rae Drive and Greenway Terrace
C5	Right	Cement	1.4	1.2	Good	Rae Drive and Greenway Terrace
C6	Right	Corrugated Metal	1.4	1.4	Good	Rae Drive and Greenway Terrace
C7	Right	Corrugated Metal	2.5	1.8	Good	Rae Drive and Sunnyslope Drive
C8	Left	Corrugated Metal	2.6	2.6	Good	North Ave and Hartbrook Drive
C9	Right	Other	0.6	0.6	Intact	Lawn Street
C10	Right	Other	0.7	0.7	Good	Lawn Street
C11	Right	Corrugated Metal	2.2	2.2	Rusted and crumbling on end	Lawn Street
C12	Right	Cement	1.5	2.5	Intact	Oak Street and Lawn Street
C13	Right	Corrugated Metal	1.5	1.4	Good	Oak Street and Lawn Street
C14	Right	Cement	3.0	2.5	Broken edges but intact	Capitol Drive and Oak Street
C15	Left	Other	1.5	1.5	Fone	Cottonwood and Park Avenue
C16	Left	Corrugated Metal	1.0	1.0	Good	Cottonwood and Park Avenue
C17	Left	Corrugated Metal	1.2	1.2	Good	Cottonwood and Park Avenue
C18	Right	Corrugated Metal	1.5	1.5	Good	Cottonwood and Park Avenue
C19	Left	Corrugated Metal	4.0	4.0	Good	Cottonwood Avenue and Railroad - Nixon Park on Right Bank
C20	Left	Cement	3.0	4.0	Good	Corner of Cottonwood Avenue and Cardinal Lane

Figure A.3
Stormwater Outfall Photographs: September 2016

Bank: Right
Material: Plastic
Condition: Good
Dimensions: 0.5 x 0.5 feet

Bank: Left
Material: Iron
Condition: Good
Dimensions: Not Measured

Bank: Left
Material: Concrete
Condition: Good
Dimensions: 3.2 x 3.2 feet

Bank: Right
Material: Concrete
Condition: Good
Dimensions: 3.0 x 1.8 feet

Figure A.3 (Continued)

Bank: Right
Material: Concrete
Condition: Good
Dimensions: 3.7 x 3.7 feet

Bank: Right
Material: Concrete
Condition: Good
Dimensions: 1.4 x 1.2 feet

Bank: Right
Material: Corrugated Steel
Condition: Good
Dimensions: 1.4 x 1.4 feet

Bank: Right
Material: Concrete
Condition: Good
Dimensions: 1.4 x 1.2 feet

Figure A.3 (Continued)

Bank: Right
Material: Corrugated Steel
Condition: Good
Dimensions: 1.4 x 1.4 feet

Bank: Right
Material: Plastic
Condition: Good
Dimensions: 0.6 x 0.6 feet

Bank: Right
Material: Plastic
Condition: Good
Dimensions: 0.7 x 0.7 feet

Bank: Right
Material: Corrugated Steel
Condition: Rusted and Cracking
Dimensions: 2.2 x 2.2 feet

Figure A.3 (Continued)

Bank: Right
Material: Concrete
Condition: Cracked
Dimensions: 1.5 x 1.5 feet

Bank: Right
Material: Corrugated Steel
Condition: Good
Dimensions: 1.5 x 1.4 feet

Bank: Right
Material: Concrete
Condition: Good
Dimensions: 3.0 x 2.5 feet

Bank: Left
Material: Plastic
Condition: Good
Dimensions: 1.5 x 1.5 feet

Figure A.3 (Continued)

Bank: Left
Material: Corrugated Steel
Condition: Good
Dimensions: 1.0 x 1.0 feet

Bank: Left
Material: Corrugated Steel
Condition: Good
Dimensions: 1.2 x 1.2 feet

Bank: Right
Material: Corrugated Steel
Condition: Good
Dimensions: 1.5 x 1.5 feet

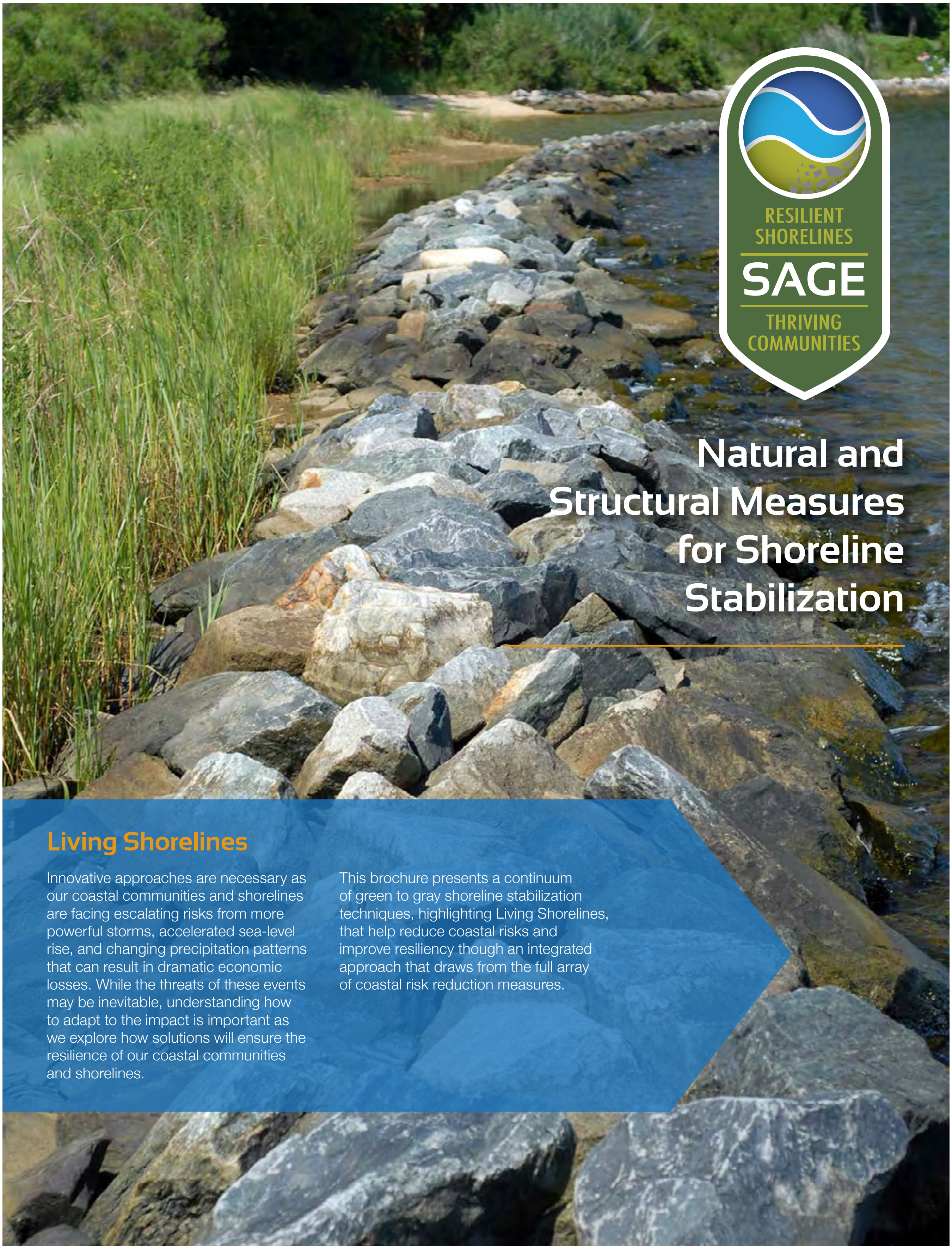
Figure A.3 (Continued)

Bank: Left
Material: Concrete
Condition: Good
Dimensions: 4.0 x 4.0 feet

Bank: Left
Material: Concrete
Condition: Good
Dimensions: 3.0 x 4.0 feet

NATURAL AND STRUCTURAL MEASURES FOR SHORELINE STABILIZATION

APPENDIX B



RESILIENT SHORELINES
SAGE
THRIVING COMMUNITIES

Natural and Structural Measures for Shoreline Stabilization

Living Shorelines

Innovative approaches are necessary as our coastal communities and shorelines are facing escalating risks from more powerful storms, accelerated sea-level rise, and changing precipitation patterns that can result in dramatic economic losses. While the threats of these events may be inevitable, understanding how to adapt to the impact is important as we explore how solutions will ensure the resilience of our coastal communities and shorelines.

This brochure presents a continuum of green to gray shoreline stabilization techniques, highlighting Living Shorelines, that help reduce coastal risks and improve resiliency though an integrated approach that draws from the full array of coastal risk reduction measures.

Coastal Risk Reduction and Living Shorelines

Coastal Risk Reduction

Coastal systems typically include both natural habitats and man-made structural features. The relationships and interactions among these features are important variables in determining coastal vulnerability, reliability, risk and resilience.

Coastal risk reduction can be achieved through several approaches, which may be used in combination with each other. Options for coastal risk reduction include:

- Natural or nature-based measures: Natural features are created through the action of physical, biological, geologic, and chemical processes operating in nature, and include marshes, dunes and oyster reefs. Nature-based features are created by human design, engineering, and construction to mimic nature. A living shoreline is an example of a nature-based feature.
- Structural measures: Structural measures include sea walls, groins and breakwaters. These features reduce coastal risks by decreasing shoreline erosion, wave damage, and flooding.
- Non-structural measures: Includes modifications in public policy, management practices, regulatory policy and pricing policy (e.g., structure acquisitions or relocations, flood proofing of structures, implementing flood warning systems, flood preparedness planning, establishment of land use regulations, emergency response plans).

The types of risk reduction measures employed depend upon the geophysical setting, the desired level of risk reduction, objectives, cost, reliability, and other factors.

SAGE – Systems Approach to Geomorphic Engineering

USACE and NOAA recognize the value of an integrated approach to risk reduction through the incorporation of natural and nature-based features in addition to non-structural and structural measures to improve social, economic, and ecosystem resilience. To promote this approach, USACE and NOAA have engaged partners and stakeholders in a community of practice called SAGE, or a Systems Approach to Geomorphic Engineering. This community of practice provides a forum to discuss science and policy that can support and advance a systems approach to implementing risk reduction measures that both sustain a healthy environment and create a resilient shoreline.

SAGE promotes a hybrid engineering approach that integrates soft or ‘green’ natural and nature-based measures, with hard or ‘gray’ structural ones at the landscape scale. These stabilization solutions include “living shoreline” approaches which integrate living components, such as plantings, with structural techniques, such as seawalls or breakwaters.

Living Shorelines achieve multiple goals, such as:

- Stabilizing the shoreline and reducing current rates of shoreline erosion and storm damage;
- Providing ecosystem services (such as habitat for fish and other aquatic species) and increasing flood storage capacity; and
- Maintaining connections between land and water ecosystems to enhance resilience.

In order to determine the most appropriate shoreline protection technique, several site-specific conditions must be assessed. The following coastal conditions, along with other factors, are used to determine the combinations of green and gray solutions for a particular shoreline.

REACH: A longshore segment of a shoreline where influences and impacts, such as wind direction, wave energy, littoral transport, etc. mutually interact.

RESILIENCE: The ability to avoid, minimize, withstand, and recover from the effects of adversity, whether natural or man made, under all circumstances of use. This definition also applies to engineering (i), ecological (ii), and community resilience (iii).

FETCH: A cross shore distance along open water over which wind blows to generate waves. For any given shore, there may be several fetch distances depending on predominant wind direction.

PHYSICAL CONDITIONS: The slope of the foreshore or beach face, a geologic condition or bathymetry offshore.

TIDAL RANGE: The vertical difference between high tide and low tide.

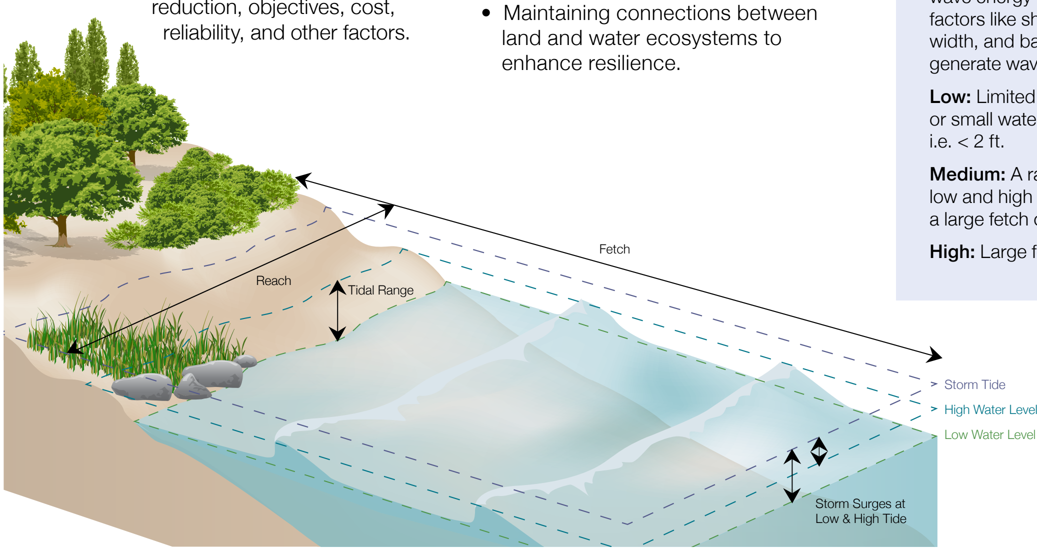
STORM SURGE: The resulting temporary rise in sea level due to the action of wind stress on the water surface and low atmospheric pressure created during storms which can cause coastal flooding. Surge is the difference from expected tide level. Storm tide is the total water level.

WAVE ENERGY: Wave energy is related to wave height and describes the force a wave is likely to have on a shoreline. Different environments will have lower or higher wave energy depending on environmental factors like shore orientation, wind, channel width, and bathymetry. Boat wakes can also generate waves.

Low: Limited fetch in a sheltered, shallow or small water body (estuary, river, bay) i.e. < 2 ft.

Medium: A range that combines elements of low and high energy (e.g., shallow water with a large fetch or partially sheltered) i.e. 2 - 5 ft.

High: Large fetch, deep water (open ocean).



2

HOW GREEN OR GRAY SHOULD YOUR SHORELINE SOLUTION BE?

GREEN - SOFTER TECHNIQUES

Small Waves | Small Fetch | Gentle Slope | Sheltered Coast

LIVING SHORELINE

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VEGETATION ONLY

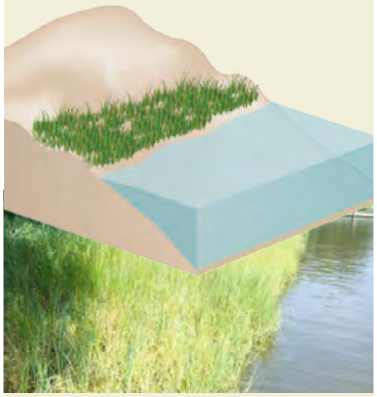

Photo Credit: Maryland Department of Natural Resources - Shoreline Conservation Service

Roots hold soil in place to reduce erosion. Provides a buffer to upland areas and breaks small waves.

Suitable For

Low wave energy environments.

Material Options

- Native plants*

Benefits

- Dissipates wave energy
- Slows inland water transfer
- Increases natural storm water infiltration
- Provides habitat and ecosystem services
- Minimal impact to natural community and ecosystem processes
- Maintains aquatic/terrestrial interface and connectivity
- Flood water storage

Disadvantages

- No storm surge reduction ability
- No high water protection
- Appropriate in limited situations
- Uncertainty of successful vegetation growth and competition with invasive

Initial Construction: ●
Operations & Maintenance: ●

EDGING

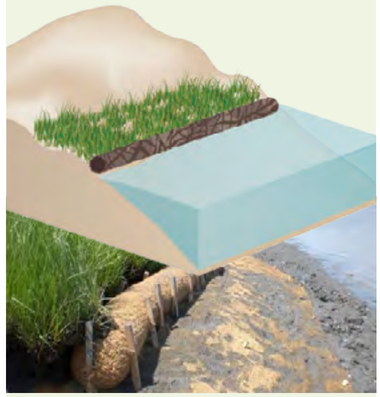

Photo Credit: Partnership for Delaware Estuary

Structure to hold the toe of existing or vegetated slope in place. Protects against shoreline erosion.

Suitable For

Most areas except high wave energy environments.

Vegetation* Base with Material Options

(low wave only, temporary)

- “Snow“ fencing
- Erosion control blankets
- Geotextile tubes
- Living reef (oyster/mussel)
- Rock gabion baskets

Benefits

- Dissipates wave energy
- Slows inland water transfer
- Provides habitat and ecosystem services
- Increases natural storm water infiltration
- Toe protection helps prevent wetland edge loss

Disadvantages

- No high water protection
- Uncertainty of successful vegetation growth and competition with invasive

Initial Construction: ●●
Operations & Maintenance: ●

SILLS

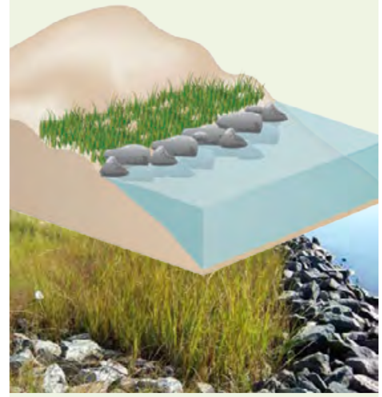

Photo Credit: Maryland Department of Natural Resources - Shoreline Conservation Service

Parallel to existing or vegetated shoreline, reduces wave energy and prevents erosion. A gapped approach would allow habitat connectivity, greater tidal exchange, and better waterfront access.

Suitable For

Most areas except high wave energy environments.

Vegetation* Base with Material Options

- Stone
- Sand breakwaters
- Living reef (oyster/mussel)
- Rock gabion baskets

Benefits

- Provides habitat and ecosystem services
- Dissipates wave energy
- Slows inland water transfer
- Provides habitat and ecosystem services
- Increases natural storm water infiltration
- Toe protection helps prevent wetland edge loss

Disadvantages

- Require more land area
- No high water protection
- Uncertainty of successful vegetation growth and competition with invasive

Initial Construction: ●●
Operations & Maintenance: ●

* Native plants and materials must be appropriate for current salinity and site conditions.

Initial Construction: ● = up to $1000 per linear foot, ●● = $1001 - $2000 per linear foot, ●●● = $2001 - $5000 per linear foot, ●●●● = $5001 - $10,000 per linear foot
Operations and Maintenance (yearly for a 50 year project life): ● = up to $100 per linear foot, ●● = $101 - $500 per linear foot, ●●● = over $500 per linear foot

3

HOW GREEN OR GRAY SHOULD YOUR SHORELINE SOLUTION BE?

GREEN - SOFTER TECHNIQUES

Small Waves | Small Fetch | Gentle Slope | Sheltered Coast

LIVING SHORELINE

CONTINUED FROM LAST PAGE

BEACH NOURISHMENT ONLY

Photo Credit: USACE New York District Public Affairs

Large volume of sand added from outside source to an eroding beach. Widens the beach and moves the shoreline seaward.

Suitable For

Low-lying oceanfront areas with existing sources of sand and sediment.

Material Options

- Sand

Benefits

- Expands usable beach area
- Lower environmental impact than hard structures
- Flexible strategy
- Redesigned with relative ease
- Provides habitat and ecosystem services

Disadvantages

- Requires continual sand resources for renourishment
- No high water protection
- Appropriate in limited situations
- Possible impacts to regional sediment transport

Initial Construction: ●●●
Operations & Maintenance: ●●

BEACH NOURISHMENT & VEGETATION ON DUNE

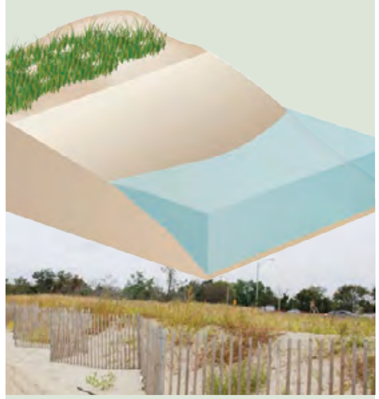

Photo Credit: USACE New York District Public Affairs

Helps anchor sand and provide a buffer to protect inland area from waves, flooding and erosion.

Suitable For

Low-lying oceanfront areas with existing sources of sand and sediment.

Material Options

Sand with vegetation
Can also strengthen dunes with:

- Geotextile tubes
- Rocky core

Benefits

- Expands usable beach area
- Lower environmental impact
- Flexible strategy
- Redesigned with relative ease
- Vegetation strengthens dunes and increases their resilience to storm events
- Provides habitat and ecosystem services

Disadvantages

- Requires continual sand resources for renourishment
- No high water protection
- Appropriate in limited situations
- Possible impacts to regional sediment transport

Initial Construction: ●●●
Operations & Maintenance: ●●

Initial Construction: ● = up to $1000 per linear foot, ●● = $1001 - $2000 per linear foot, ●●● = $2001 - $5000 per linear foot, ●●●● = $5001 - $10,000 per linear foot 4
Operations and Maintenance (yearly for a 50 year project life): ● = up to $100 per linear foot, ●● = $101 - $500 per linear foot, ●●● = over $500 per linear foot

HOW GREEN OR GRAY SHOULD YOUR SHORELINE SOLUTION BE?

GRAY - HARDER TECHNIQUES

Large Waves | Large Fetch | Steep Slope | Open Coast

COASTAL STRUCTURE

BREAKWATER

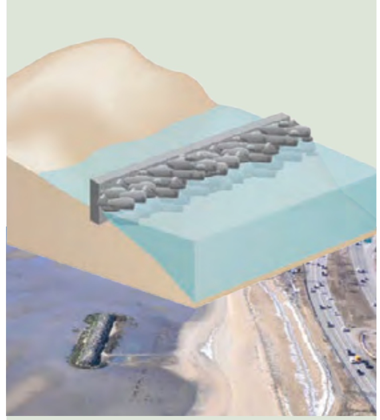

Photo Credit: USACE New York District Public Affairs

Offshore structures intended to break waves, reducing the force of wave action and encourages sediment accretion. Can be floating or fixed to the ocean floor, attached to shore or not, and continuous or segmented. A gapped approach would allow habitat connectivity, greater tidal exchange, and better waterfront access.

Suitable For

Most areas except high wave energy environments often in conjunction with marinas.

Material Options

- Grout-filled fabric bags
- Armorstone
- Pre-cast concrete blocks
- Living reef (oyster/mussel) if low wave environment
- Wood
- Rock†

Benefits

- Reduces wave force and height
- Stabilizes wetland
- Can function like reef
- Economical in shallow areas
- Limited storm surge flood level reduction

Disadvantages

- Expensive in deep water
- Can reduce water circulation (minimized if floating breakwater is applied)
- Can create navigational hazard
- Require more land area
- Uncertainty of successful vegetation growth and competition with invasive
- No high water protection
- Can reduce water circulation
- Can create navigation hazard

GROIN

Photo Credit: USACE New York District Public Affairs

Perpendicular, projecting from shoreline. Intercept water flow and sand moving parallel to the shoreline to prevent beach erosion and break waves. Retain sand placed on beach.

Suitable For

Coordination with beach nourishment.

Material Options

- Concrete/stone rubble†
- Timber
- Metal sheet piles

Benefits

- Protection from wave forces
- Methods and materials are adaptable
- Can be combined with beach nourishment projects to extend their life

Disadvantages

- Erosion of adjacent sites
- Can be detrimental to shoreline ecosystem (e.g. replaces native substrate with rock and reduces natural habitat availability)
- No high water protection

† Rock/stone needs to be appropriately sized for site specific wave energy.

CONTINUED ON NEXT PAGE

GRAY CAN BE GREENER: e.g., 'Living Breakwater' using oysters to colonize rocks or 'Greenwall/Biowall' using vegetation, alternative forms and materials

Breakwater — Initial Construction: ●●●● Operations & Maintenance: ●●●

Groin — Initial Construction: ●●● Operations & Maintenance: ●●

Initial Construction: ● = up to $1000 per linear foot, ●● = $1001 - $2000 per linear foot, ●●● = $2001 - $5000 per linear foot, ●●●● = $5001 - $10,000 per linear foot
Operations and Maintenance (yearly for a 50 year project life): ● = up to $100 per linear foot, ●● = $101 - $500 per linear foot, ●●● = over $500 per linear foot

HOW GREEN OR GRAY SHOULD YOUR SHORELINE SOLUTION BE?

GRAY - HARDER TECHNIQUES

Large Waves | Large Fetch | Steep Slope | Open Coast

COASTAL STRUCTURE

CONTINUED FROM LAST PAGE

REVETMENT

Photo Credit: Maryland Department of Natural Resources - Shoreline Conservation Service

Lays over the slope of a shoreline. Protects slope from erosion and waves.

Suitable For

Sites with pre-existing hardened shoreline structures.

Material Options

- Stone rubble‡
- Concrete blocks
- Cast concrete slabs
- Sand/concrete filled bags
- Rock-filled gabion basket

Benefits

- Mitigates wave action
- Little maintenance
- Indefinite lifespan
- Minimizes adjacent site impact

Disadvantages

- No major flood protection
- Require more land area
- Loss of intertidal habitat
- Erosion of adjacent unreinforced sites
- Require more land area
- No high water protection
- Prevents upland from being a sediment source to the system

‡ Rock/stone needs to be appropriately sized for site specific wave energy.

BULKHEAD

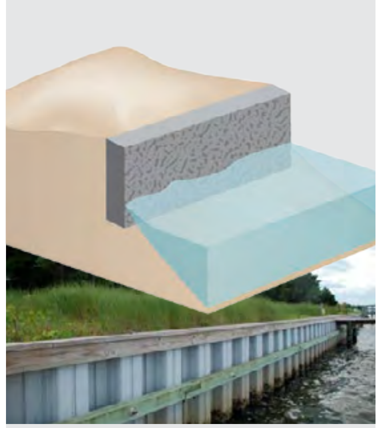

Photo Credit: North Carolina Department of Environment and Natural Resources

Parallel to the shoreline, vertical retaining wall. Intended to hold soil in place and allow for a stable shoreline.

Suitable For

High energy settings and sites with pre-existing hardened shoreline structures. Accommodates working water fronts (eg: docking for ships and ferries).

Material Options

- Steel sheet piles
- Timber
- Concrete
- Composite carbon fibers
- Gabions

Benefits

- Moderates wave action
- Manages tide level fluctuation
- Long lifespan
- Simple repair

Disadvantages

- No major flood protection
- Erosion of seaward seabed
- Erosion of adjacent unreinforced sites
- Loss of intertidal habitat
- May be damaged from overtopping oceanfront storm waves
- Prevents upland from being a sediment source to the system
- Induces wave reflection

SEAWALL

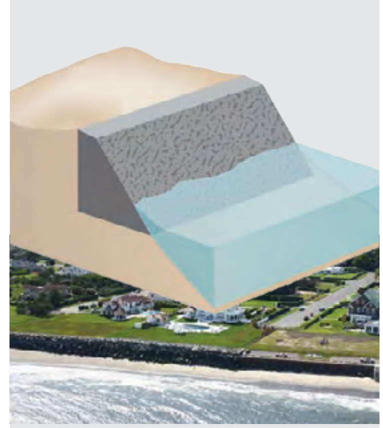

Photo Credit: USACE New York District Public Affairs

Parallel to shoreline, vertical or sloped wall. Soil on one side of wall is the same elevation as water on the other. Absorbs and limits impacts of large waves and directs flow away from land.

Suitable For

Areas highly vulnerable to storm surge and wave forces.

Material Options

- Stone
- Rock
- Concrete
- Steel/vinyl sheets
- Steel sheet piles

Benefits

- Prevents storm surge flooding
- Resists strong wave forces
- Shoreline stabilization behind structure
- Low maintenance costs
- Less space intensive horizontally than other techniques (e.g. vegetation only)

Disadvantages

- Erosion of seaward seabed
- Disrupt sediment transport leading to beach erosion
- Higher up-front costs
- Visually obstructive
- Loss of intertidal zone
- Prevents upland from being a sediment source to the system
- May be damaged from overtopping oceanfront storm waves

GRAY CAN BE GREENER: e.g., 'Living Breakwater' using oysters to colonize rocks or 'Greenwall/Biowall' using vegetation, alternative forms and materials

	Revetment	Bulkhead	Seawall
Initial Construction	●●●●	●●●	●●●●
Operations & Maintenance	●●	●●	●●●

Initial Construction: ● = up to $1000 per linear foot, ●● = $1001 - $2000 per linear foot, ●●● = $2001 - $5000 per linear foot, ●●●● = $5001 - $10,000 per linear foot
Operations and Maintenance (yearly for a 50 year project life): ● = up to $100 per linear foot, ●● = $101 - $500 per linear foot, ●●● = over $500 per linear foot

Is a Living Shoreline a Good Fit for What I Need?

Living Shorelines achieve multiple goals such as:

- Stabilizing the shoreline and reducing current rates of shoreline erosion and storm damage
- Providing ecosystem services, such as habitat for fish and other aquatic species and increasing flood storage capacity
- Maintaining connections between land and water ecosystems to enhance resilience

Site-specific conditions will influence your choice of shoreline protection technique (ex: wave energy level, fetch lengths, rate and pattern of erosion, etc). Here are some additional factors to keep in mind as you consider Living Shorelines.

WHAT ARE THE BENEFITS?

- Erosion control and shore stabilization.
- Restored and enhanced habitat which supports fish and wildlife populations.
- Increased property values.
- Enhanced community enjoyment.
- Opportunities for education.
- Improved public access to waterfront through recreational activities such as fishing, boating and birding. Can be used to satisfy zoning and permitting requirement for waterfront development projects.
- Complemented natural shoreline dynamics & movement; increased resilience and absorption of wave energy, storm surge and floodwaters; and an adaptive tool for preparation of sea level rise.
- Improved water quality from settling or trapping sediment (e.g. once established, a marsh can filter surface water runoff or oysters can provide coastal water filtration).

WHAT ARE SOME CHALLENGES?

- Uncertainty in risk because of lack of experience of techniques.
- Public funds are often tied to government permit compliance.
- Permitting processes can be lengthy and challenging. The existing regulatory process is centered on traditional "gray" or "hard" techniques. Regulators and project sponsors alike are learning how to design living shorelines projects. Talk with someone about your state's permitting process or to hear about their experiences.
- It takes time to develop and test new shoreline protection methods.
- There may be land ownership constraints. Consider where federal and state jurisdiction for the water body starts and ends.
- In urban environments, there is limited land (bulkheads may seem like the only option), a variety of upland uses (industrial past use may have left legacy contaminants) and high velocity waters.
- The overall sediment system needs to be taken into account to protect neighboring properties from experiencing starved down drift shorelines or other consequences as a result of a project.
- Lack of public awareness of performance and benefits of living shorelines.
- Not all techniques have the same level of performance or success monitoring. Less practiced techniques may require more monitoring.

WHAT INFLUENCES COST?

- The materials chosen for the project influence cost.
- Including green techniques can be cheaper than traditional gray techniques.
- Sometimes it's possible to install the project yourself, other times you will need help from a professional.
- Long term maintenance is required as any landscape project (e.g. replanting may be needed after a storm).

HOW TO FIND OUT MORE

If you have a Living Shorelines permitting question, contact your state's office of Environmental Protection, Conservation or Natural Resources, your coastal zone manager such as your state's Department of State, as well as your local U.S. Army Corps of Engineers (USACE) district office.

If you would like science or engineering advice, or to talk to people who have experience studying or constructing living shorelines, reach out to some of the following: your local universities, your City's Department of Planning and Department of Parks, Sea Grant Chapter, Littoral Society, The Nature Conservancy, The Trust for Public Land, The Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), USACE, engineering firms and other organizations that focus on your local waterfront.

These and other websites are good references to learn more about Living Shorelines:

SAGE
www.SAGEcoast.org

NOAA Restoration
www.habitat.noaa.gov/livingshorelines

USACE Engineer Research Development Center, Engineering with Nature
el.erdc.usace.army.mil/ewn

USACE North Atlantic Division, National Planning Center of Expertise for Coastal Storm Damage Reduction
www.nad.usace.army.mil/About/NationalCentersofExpertise/CoastalStormDamageReduction(Planning).aspx

Virginia Institute of Marine Science (VIMS) Center for Coastal Resources Management
ccrm.vims.edu/livingshorelines/index.html

Coasts, Oceans, Ports & Rivers Institute (COPRI)
www.mycopri.org/livingshorelines

The Nature Conservancy
www.nature.org/ourinitiatives/habitats/oceanscoasts/howwework/helping-oceans-adapt-to-climate-change.xml

US Army Corps of Engineers®

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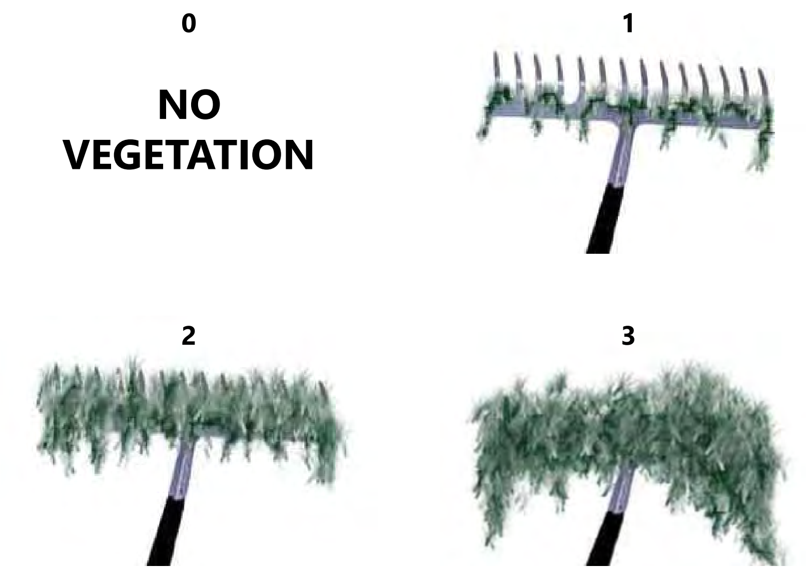
APPENDIX C

NAGAWICKA LAKE 2016 AQUATIC PLANT SURVEY PLANT SPECIES DISTRIBUTION MAPS

Figure C.1
Rake Fullness Ratings



Source: Wisconsin Department of Natural Resources and SEWRPC

SOURCES OF INFORMATION:

Borman, S., Korth, R., & Temte, J. (2014). Through the Looking Glass: A Field Guide to Aquatic Plants, Second Edition. Stevens Point, WI, USA: Wisconsin Lakes Partnership.

Robert W. Freckman Herbarium: wisplants.uwsp.edu

Skawinski, P. M. (2014). Aquatic Plants of the Upper Midwest: A Photographic Field Guide to Our Underwater Forests, Second Edition. Wausau, Wisconsin, USA: Self-Published.

University of Michigan Herbarium: michiganflora.net/home.aspx

UW-System WisFlora. 2016. wisflora.herbarium.wisc.edu/index.php

Native

COONTAIL

Ceratophyllum demersum

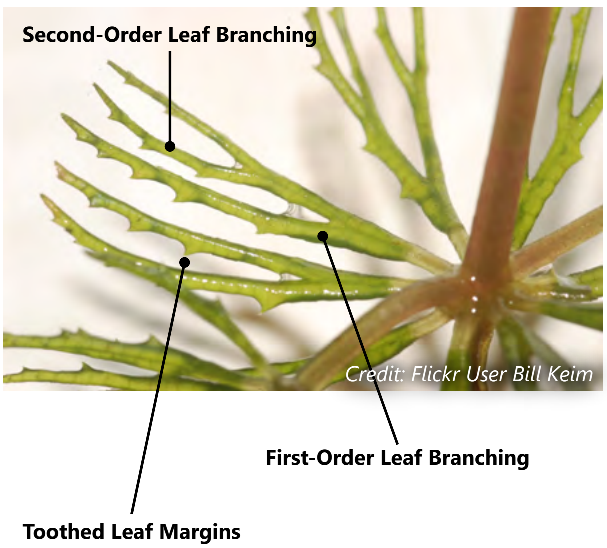
Identifying Features

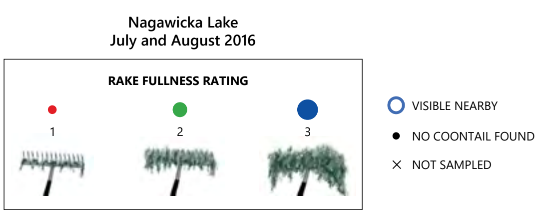
- Often bushy near tips of branches, giving the raccoon tail-like appearance ("coontail")
- Whorled leaves with one to two orders of
- branching and small teeth on their margins
- Flowers (rare) small and produced in leaf axils

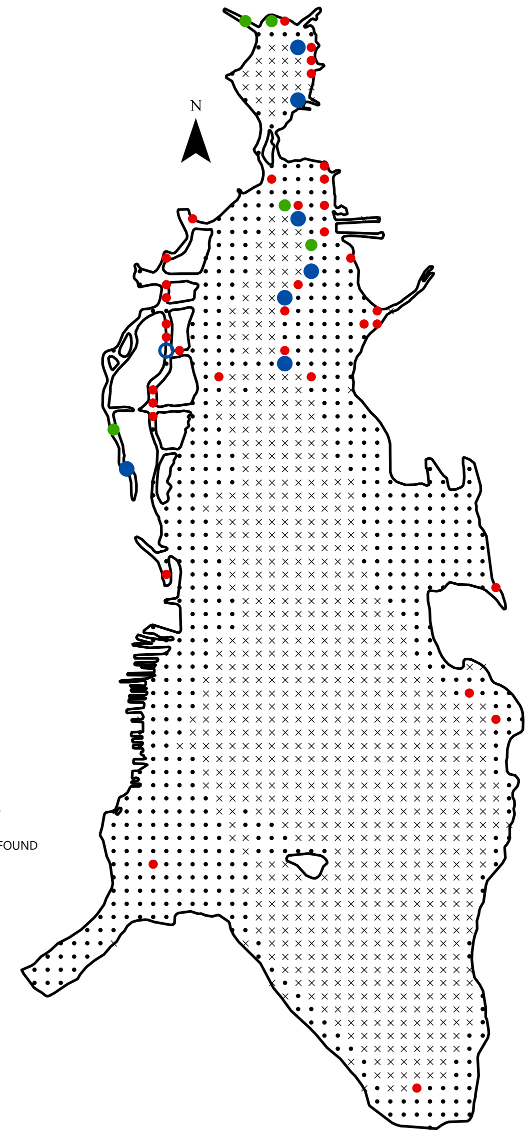
Coontail is similar to spiny hornwort (C. echinatum) and muskgrass (Chara spp.), but spiny hornwort has some leaves with three to four orders of branching, and coontail does not produce the distinct garlic-like odor of muskgrass when crushed

Ecology

- Common in lakes and streams, both shallow and deep
- Tolerates poor water quality (high nutrients, chemical pollutants) and disturbed conditions
- Stores energy as oils, which can produce slicks on the water surface when plants decay
- Anchors to the substrate with pale, modified leaves rather than roots
- Eaten by waterfowl, turtles, carp, and muskrat







Native

MUSKGRASSES
Chara spp.

Credit: Flickr User Jeremy Halls

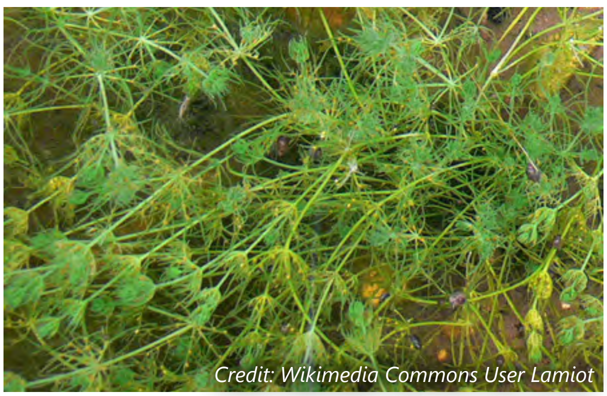
Identifying Features

- Leaf-like, ridged side branches develop in whorls of six or more
- Often encrusted with calcium carbonate, which appears white upon drying (see photo below)
- Yellow reproductive structures develop along the whorled branches in summer
- Emits a garlic-like odor when crushed

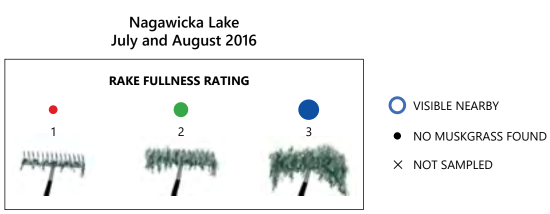
Stoneworts (*Nitella* spp.) are similar large algae, but their branches are smooth rather than ridged and more delicate

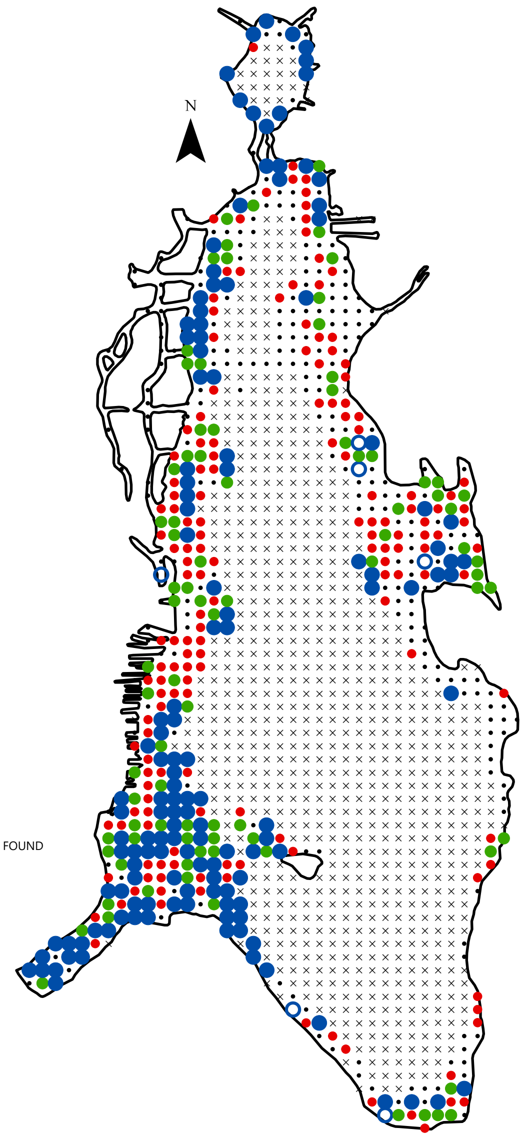
Ecology

- Found in shallow or deep water over marl or silt, often growing in large colonies in hard water
- Overwinters as rhizoids (cells modified to act as roots) or fragments
- Stabilizes bottom sediments, often among the first species to colonize open areas
- Food for waterfowl and excellent habitat for small fish



Credit: Wikimedia Commons User Lamiot





Native

COMMON WATERWEED

Elodea canadensis

Credit: Flickr User Corey Raimond

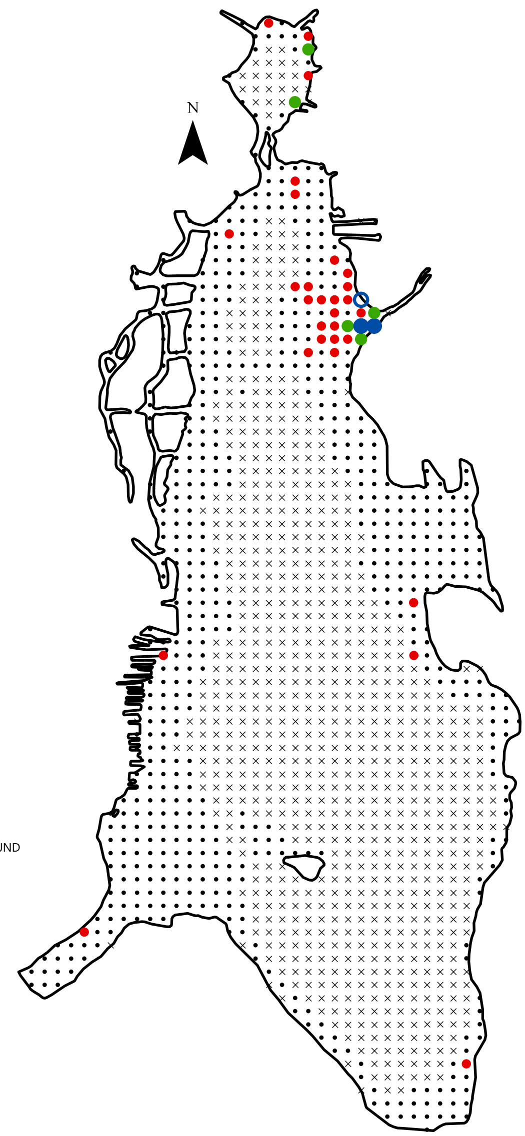
Identifying Features

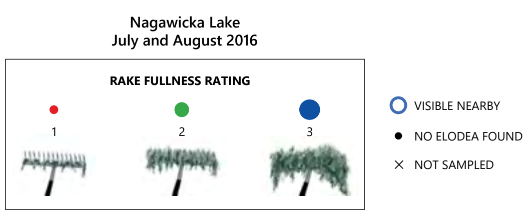
- Slender stems, occasionally rooting
- Leaves lance-shaped, in whorls of three (rarely two or four), 6.0 to 17 mm long and averaging 2.0 mm wide
- When present, tiny male and female flowers on separate plants (females more common), raised to the surface on thread-like stalks

Ecology

- Found in lakes and streams over soft substrates tolerating pollution, eutrophication and disturbed conditions
- Often overwinters under the ice
- Produces seeds only rarely, spreading primarily via stem fragments
- Provides food for muskrat and waterfowl
- Habitat for fish or invertebrates, although dense stands can obstruct fish movement

Credit: Wikimedia Commons User Christian Fischer





Native

WATER STARGRASS

Heteranthera dubia

Credit: Wikimedia Commons User Fritzflohrreynolds

Identifying Features

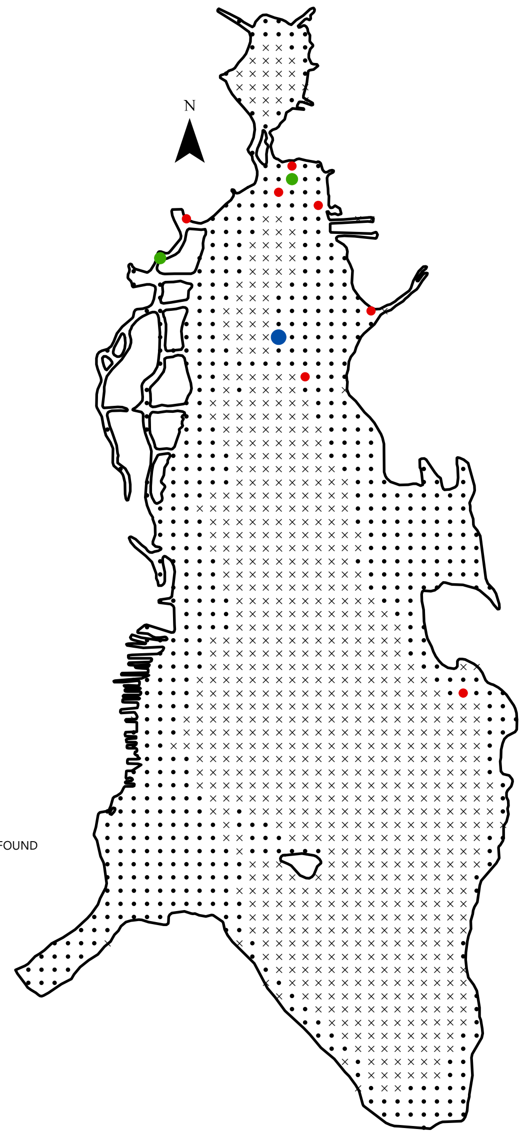
- Stems slender, slightly flattened, and branching
- Leaves narrow, alternate, with no stalk, and lacking a prominent midvein
- When produced, flowers conspicuous, yellow, and star-shaped (usually in shallow water) or inconspicuous and hidden in the bases of submersed leaves (in deeper water)

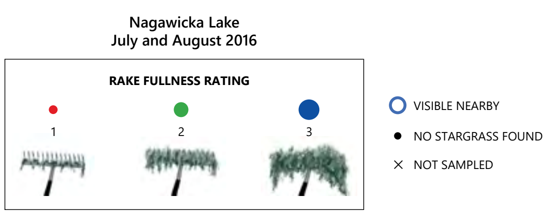
Yellow stargrass may be confused with pondweeds that have narrow leaves, but it is easily distinguished by its lack of a prominent midvein and, when present, yellow blossoms

Ecology

- Found in lakes and streams, shallow and deep
- Tolerates somewhat turbid waters
- Overwinters as perennial rhizomes
- Limited reproduction by seed
- Provides food for waterfowl and habitat for fish

Credit: Flickr User Jill Lee





Native

SMALL, FORKED, AND PERENNIAL DUCKWEED

Lemna spp.

Credit: Wikimedia Commons User Mokkie

Identifying Features

- Free-floating, green, round fronds
- May have several fronds in a cluster, but each frond has only one root
- Small Duckweed (*L. minor*) is smooth and flat on the top
- Forked Duckweed (*L. trisulca*) has pointed fronds, giving it an "oar and rowboat" appearance
- Perennial Duckweed (*L. turionifera*) has a row of small bumps down the middle

Ecology

- Free-floating duckweed is not dependent on depth, sediment type, or water clarity
- Associated with eutrophic waters

L. minor

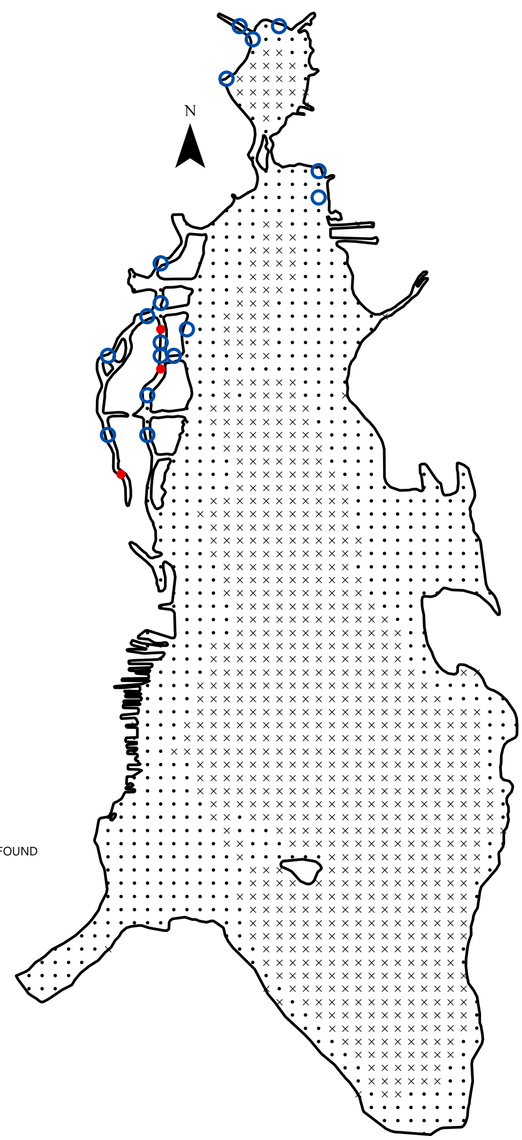
Credit: Flickr User Andreas Rockstein

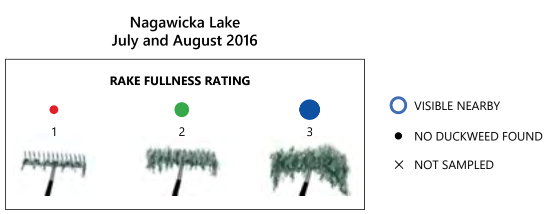
L. trisulca

Credit: Wikimedia Commons User Petr Filippov

L. turionifera

Credit: Wikimedia Commons User Stefan.lefnaer





Nonnative/ Exotic

PURPLE LOOSESTRIFE
Lythrum salicaria


Credit: Wikimedia Commons User Liz West

Identifying Features

- Terrestrial or semi-aquatic, emergent forb
- Stems often angled with four, five, or more sides, and growing one to two meters tall
- Flowers deep pink or purple, six-parted, 12 to 25 mm wide, and in groups
- Leaves lance-like, four to 11 cm long and either opposite or in whorls of three

Purple loosestrife, if small, is similar to winged loosestrife (Lythrum alatum), but winged loosestrife differs in having leaves generally smaller (<5.0 cm long), leaves mostly alternate (only lower leaves opposite), and flowers mostly held singly in the leaf axils rather than in pairs or groups

Ecology/Control

- Found in shallows, along shores, and in wet to moist meadows and prairies
- Invasive and continues to escape from ornamental plantings
- Galerucella beetles have been successfully used to control purple loosestrife. Plants may also be dug or pulled when small, but they subsequently should be placed in a landfill or burned. Several herbicides are effective, but application near water may require permits and aquatic-use formulas


Credit: Wikimedia Commons User Liz West


Credit: Paul Skawinski


Credit: Consortium of Wisconsin Herbaria

Native

VARIOUS-LEAVED WATERMILFOIL

Myriophyllum heterophyllum

Credit: Wikimedia Commons User Leslie J. Mehrhoff

Identifying Features

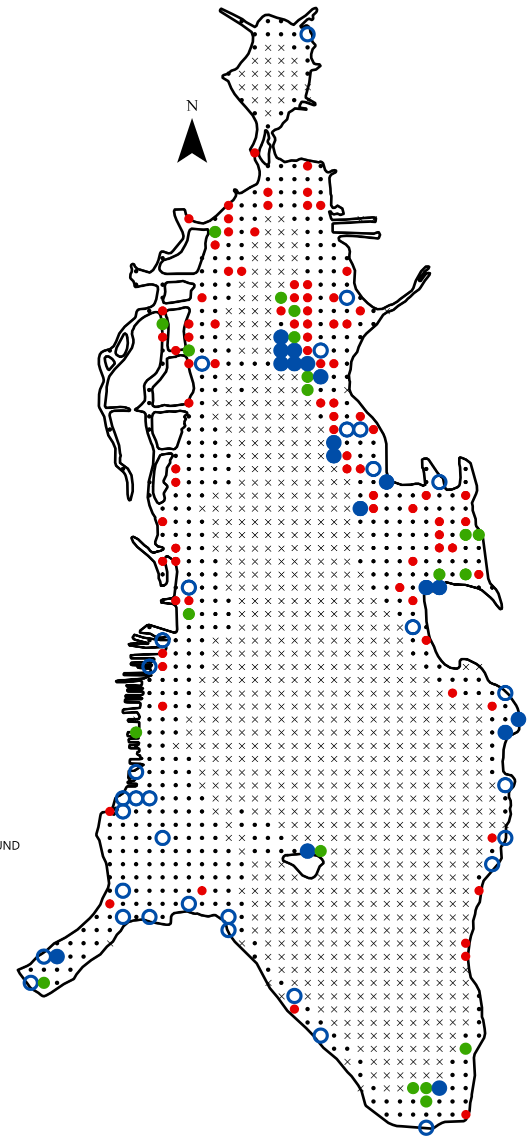
- Very short internodes lead to very bushy appearance
- Leaves in whorls of four to six, with some scattered on stem, divided into seven to 14 pairs of leaflets
- No winter buds are formed
- Flower bracts are larger than flowers and have smooth or slightly serrated edges

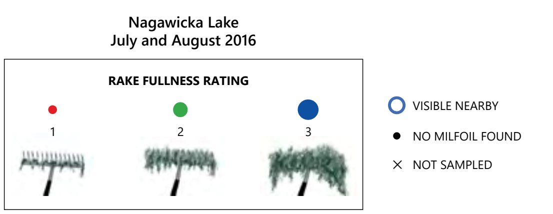
Various-leaved watermilfoil is similar to other water milfoils. Eurasian watermilfoil (*M. spicatum*) tends to be less bushy, limp out of water, and produce more leaflets per leaf

Ecology

- Found in lakes and streams, up to 15 feet but mostly shallower
- Plants on wet shorelines may produce deeply serrate "terrestrial" leave or bracts
- Consumed by waterfowl
- Provides habitat for aquatic invertebrates and shade, shelter, and foraging for fish

Credit: Wikimedia Commons User Leslie J. Mehrhoff





Nonnative/ Exotic

EURASIAN WATERMILFOIL

Myriophyllum spicatum

Credit: Paul Skawinski

Identifying Features

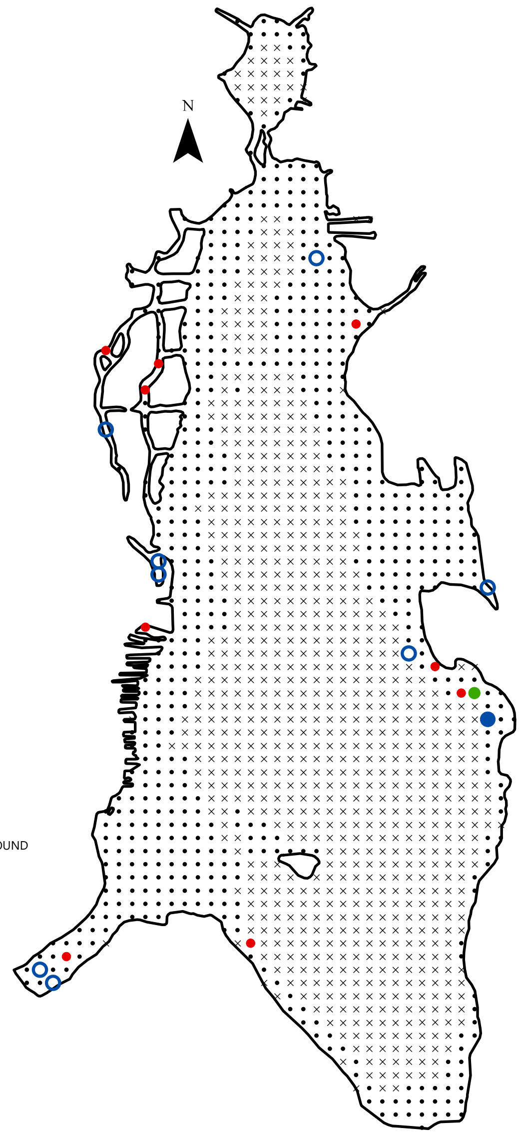
- Stems spaghetti-like, often pinkish, growing long with many branches near the water surface
- Leaves with 12 to 21 pairs of leaflets
- Produces no winter buds (turions)

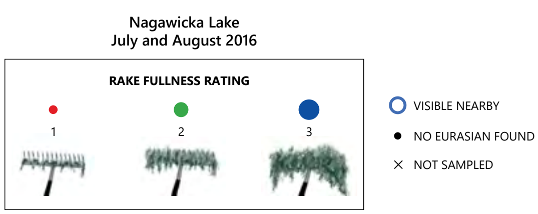
Eurasian watermilfoil is similar to northern watermilfoil (*M. sibiricum*). However, northern watermilfoil has five to 12 pairs of leaflets per leaf and stouter white or pale brown stems

Credit: Paul Skawinski

Ecology

- Hybridizes with northern (native) watermilfoil, resulting in plants with intermediate characteristics
- Invasive, growing quickly, forming canopies, and getting a head-start in spring due to an ability to grow in cool water
- Grows from root stalks and stem fragments in both lakes and streams, shallow and deep; tolerates disturbed conditions
- Provides some forage to waterfowl, but supports fewer aquatic invertebrates than mixed stands of aquatic vegetation





Native

BUSHY PONDWEED OR SLENDER NAIAD

Najas flexilis

Credit: Flickr User Tab Tannery

Identifying Features

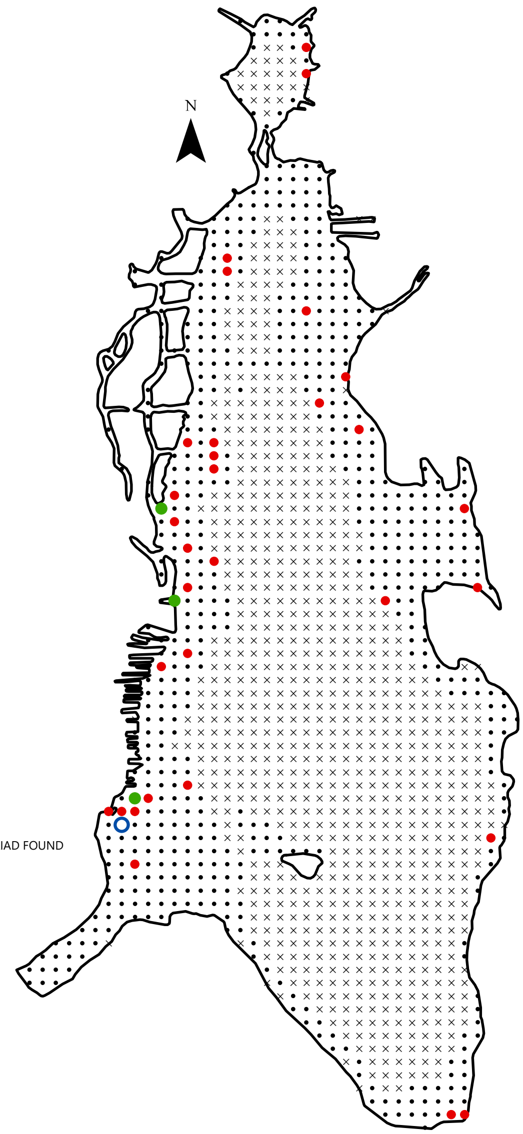
- Leaves narrow (0.4 to 1.0 mm) and pointed with broader bases where they attach to the stem and finely serrated margins
- Flowers, when present, tiny and located in leaf axils
- Variable size and spacing of leaves, as well as compactness of plant, depending on growing conditions

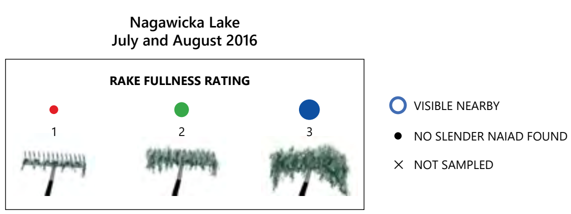
Two other Najas occur in southeastern Wisconsin. Southern naiad (N. guadalupensis) has wider leaves (to 2.0 mm). Spiny naiad (N. marina) has coarsely toothed leaves with spines along the midvein below

Ecology

- In lakes and streams, shallow and deep, often in association with wild celery
- One of the most important forages of waterfowl
- An annual plant that completely dies back in fall and regenerates from seeds each spring; also spreading by stem fragments during the growing season

Credit: Wikimedia Commons User Robert H. Mohlenbrock





Nonnative/ Exotic

SPINY NAIAD
Najas marina

Credit: Wikimedia Commons User Pascale Guinchard

Identifying Features

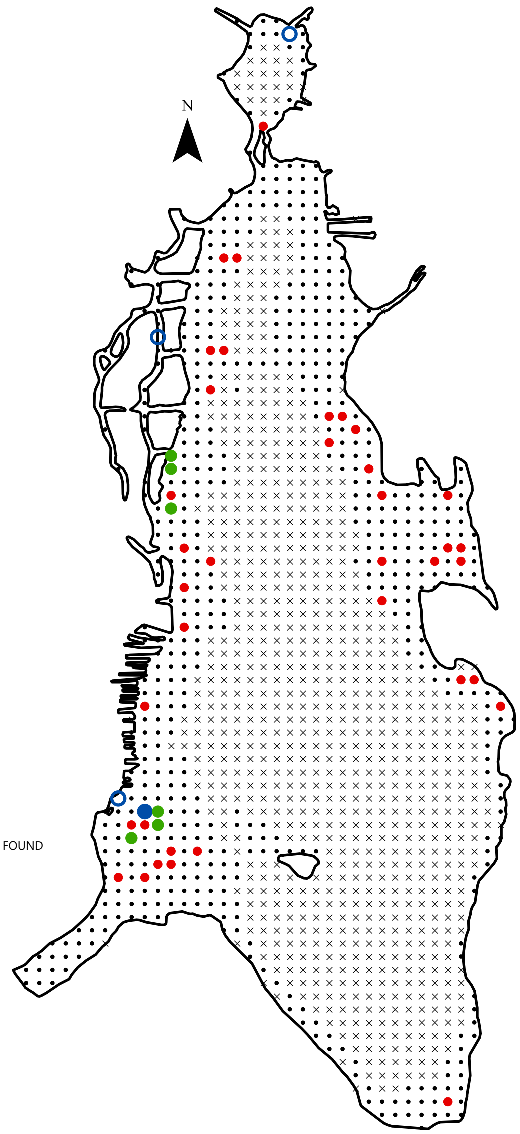
- Stems stiff and spiny, often branching many times
- Leaves stiff, 1.0 to 4.0 mm thick, with coarse teeth along the margins and midvein on the underside

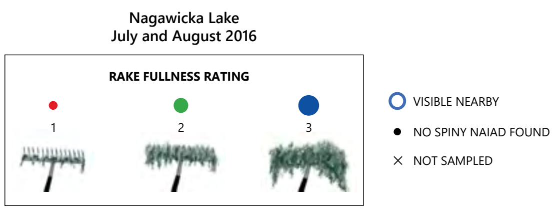
Spiny naiad is quite distinct from other naiads due to its larger, coarsely toothed leaves and the irregularly pitted surface of its fruits. Spiny naiad is presumably introduced in Wisconsin, but it is considered native in other states, including Minnesota

Ecology

- Alkaline lakes, water quality ranging from good to poor
- An annual, regenerating from seed each year
- Occurs as separate male and female plants
- Capable of growing aggressively

Credit: Wikimedia Commons User Kristian Peters





Native

SPATTERDOCK

Nuphar variegata

Credit: Wikimedia Commons User Cephas

Identifying Features

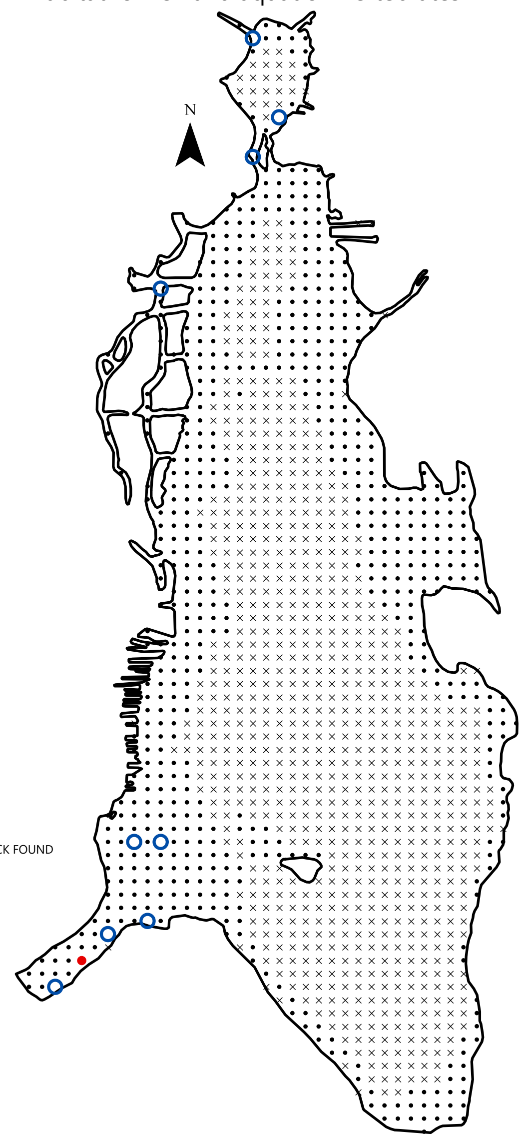
- Leaf stalks winged in cross-section
- Most leaves floating on the water surface, heart-shaped, and notched, with rounded lobes at the base
- Yellow flowers, 2.5 to 5.0 cm wide, often with maroon patches at the bases of the sepals (petal-like structures) when viewed from above

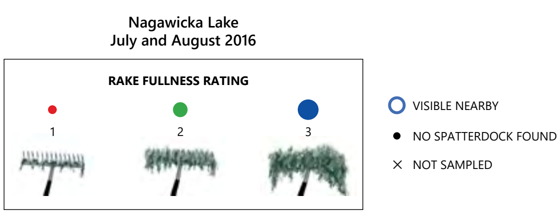
Unlike spatterdock, the similar yellow pond lily (Nuphar advena) has leaf stalks that are not winged in cross-section, leaves that more often emerge above the water surface, and leaf lobes that are more pointed. Spatterdock is superficially similar to water lilies (Nymphea spp.), but it has yellow versus white flowers and leaves somewhat heart-shaped versus round. American lotus (Nelumbo lutea) is also similar, but its leaves are round and un-notched, and its flowers are much larger

Credit: Flickr User Jason Hollinger

Ecology

- In sun or shade and mucky sediments in shallows and along the margins of ponds, lakes, and slow-moving streams
- Overwinters as a perennial rhizome
- Flowers opening during the day, closing at night, and with the odor of fermented fruit
- Buffers shorelines
- Provides food for waterfowl (seeds), deer (leaves and flowers), and muskrat, beaver, and porcupine (rhizomes)
- Habitat for fish and aquatic invertebrates





Native

WHITE WATER LILY

Nymphaea odorata

Credit: Flickr User Ryan Hodnett

Identifying Features

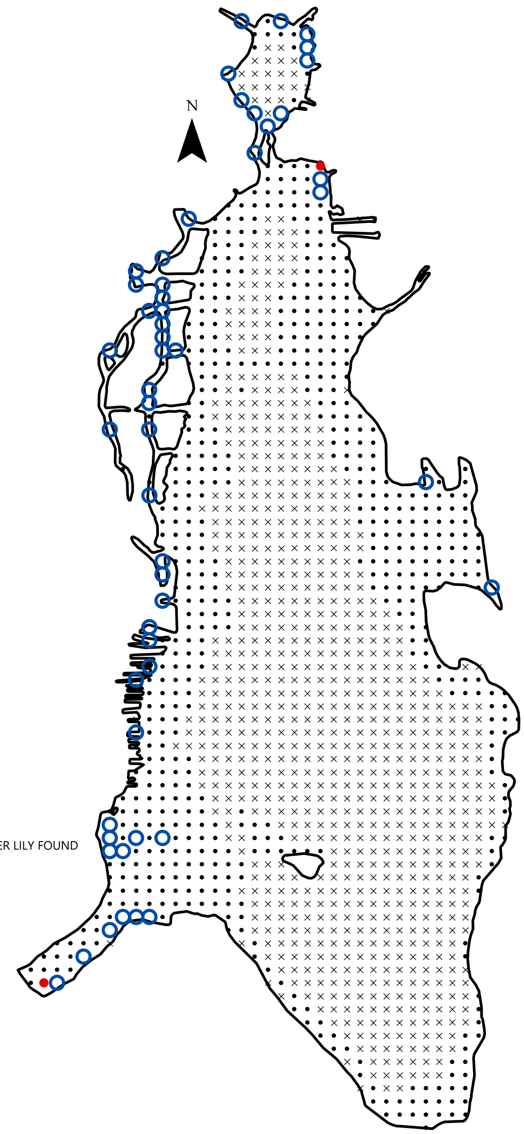
- Leaf stalks round in cross-section with four large air passages
- Floating leaves round (four to 12 inches wide under favorable conditions), *with a notch* from the outside to the center, and reddish-purple underneath
- Flowers white with a yellow center, three to nine inches wide

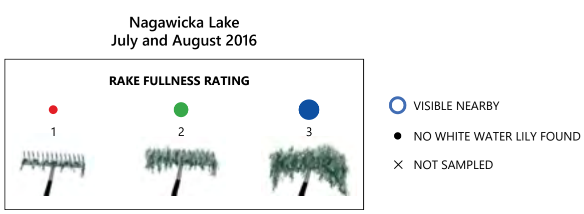
Pond lilies (*Nuphar* spp.) are superficially similar, but have yellow flowers and leaves somewhat heart-shaped. American lotus (*Nelumbo lutea*) is also similar, but its leaves are unnotched

Ecology

- Found in shallow waters over soft sediments
- Leaves and flowers emerge from rhizomes
- Flowers opening during the day, closing at night
- Seeds consumed by waterfowl, rhizomes consumed by mammals

Credit: Wikimedia Commons User Kurt Stüber





Native/ Exotic

CURLY-LEAF PONDWEED

Potamogeton crispus

Credit: Paul Skawinski

Identifying Features

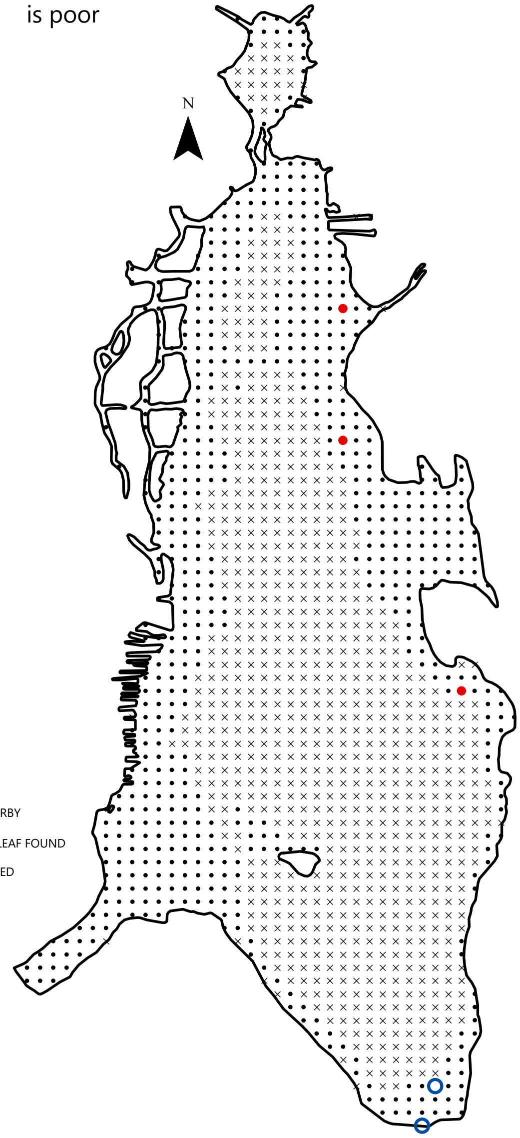
- Stems slightly flattened and both stem and leaf veins often somewhat pink
- Leaf margins very wavy and finely serrated
- Stipules (3.0 to 8.0 mm long) partially attached to leaf bases, disintegrating early in the season
- Produces pine cone-like overwintering buds (turions)

Curly-leaf pondweed may resemble clasping-leaf pondweed (*P. richardsonii*), but the leaf margins of the latter are not serrated

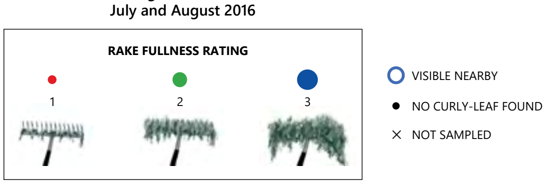
Ecology

- Found in lakes and streams, both shallow and deep
- Tolerant of low light and turbidity
- Disperses mainly by turions
- Adapted to cold water, growing under the ice while other plants are dormant, but dying back during mid-summer in warm waters
- Produces winter habitat, but mid-summer die-offs can degrade water quality and cause algal blooms
- Maintaining or improving water quality can help control this species, because it has a competitive advantage over native species when water clarity is poor

Credit: Paul Skawinski



Nagawicka Lake
July and August 2016



Native

FRIES' PONDWEED
Potamogeton friesii

Credit: Flickr User Lliam Rooney

Identifying Features

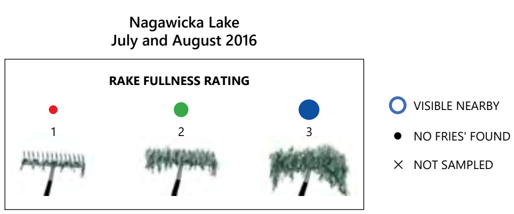
- Slender stems slightly compressed
- Submerged leaves linear with no petiole, one row of lacunar cells on each side of midvein, and 5-7 veins
- Tip of leaf rounded with short bristle
- Winter bud fan shaped and in two planes, with inner leaves at 90 degrees from outer leaves

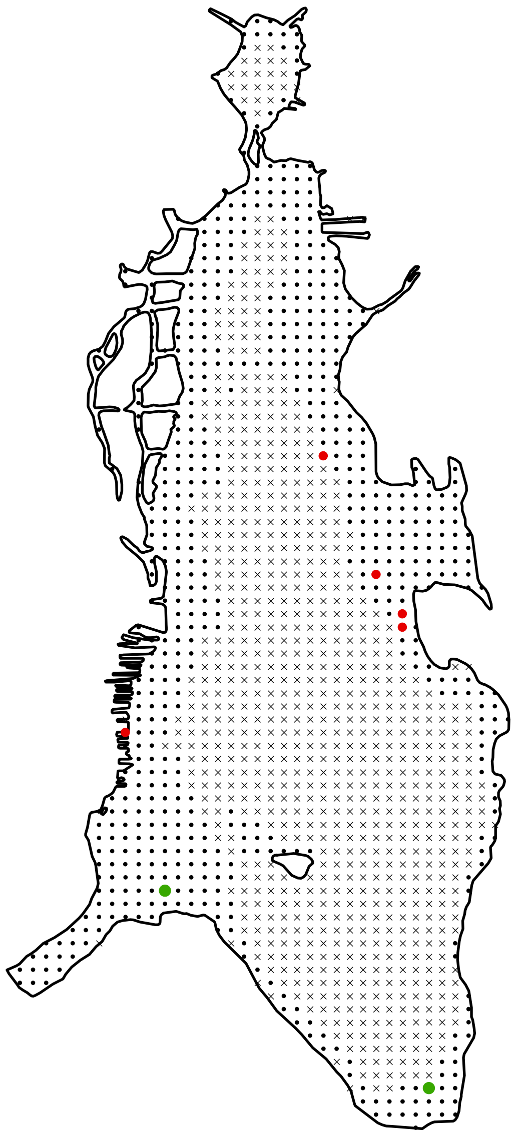
Fries' pondweed is similar to other narrow-leaved pondweeds such as small pondweed (*P. pusillis*) and stiff pondweed (*P. strictifolius*) but other narrow pondweeds do not create a fan shaped winter bud

Ecology

- Common in calcareous lakes and slow-moving streams
- Overwinters largely as winter buds (turions)
- Provides food for waterfowl,
- Provides habitat for fish and aquatic invertebrates

Credit: Flickr User Brenton Butterfield





Native

VARIABLE PONDWEED

Potamogeton gramineus

Credit: Wikimedia Commons User Tristan He

Identifying Features

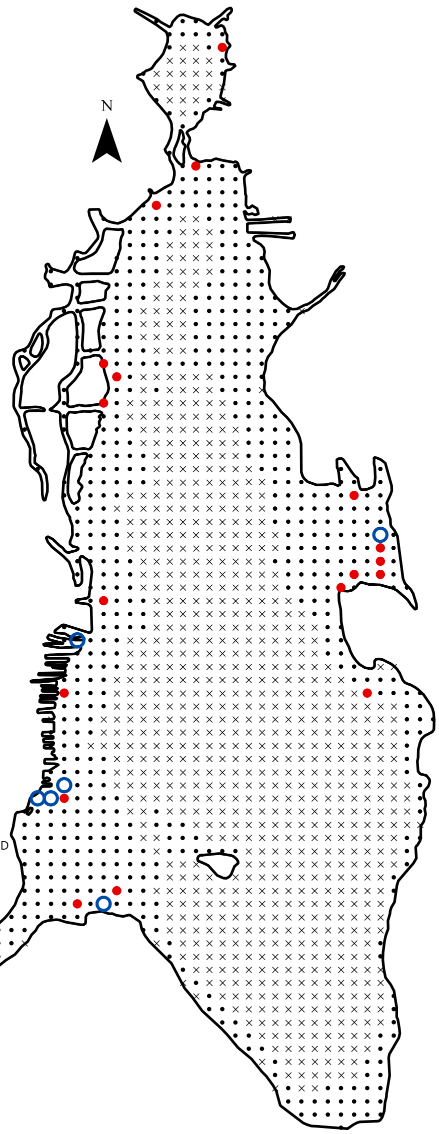
- Often heavily branched
- Submerged leaves narrow to lance-shaped, with three to seven veins, smooth margins, without stalks, but the blade tapering to the stem
- Floating leaves with 11 to 19 veins and a slender stalk that is usually longer than the blade
- Often covered with calcium carbonate in hard water

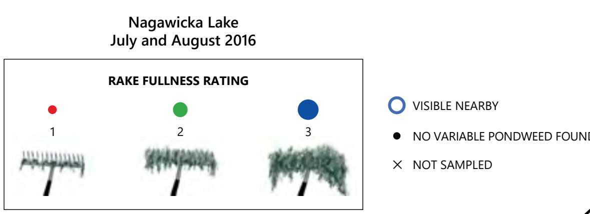
Variable pondweed is similar to Illinois pondweed (*P. illinoensis*), but Illinois pondweed has submerged leaves with nine to 19 veins

Ecology

- Shallow to deep water, often with muskgrass, wild celery, and/or slender naiad; requires more natural areas that receive little disturbance
- Overwinters as rhizomes or winter buds (turions)
- Provides food for waterfowl, muskrat, deer, and beaver
- Provides habitat for fish and aquatic invertebrates

Credit: Flickr User Jason Hollinger





Native

ILLINOIS PONDWEED

Potamogeton illinoensis

Credit: Flickr User Dick Culbert

Identifying Features

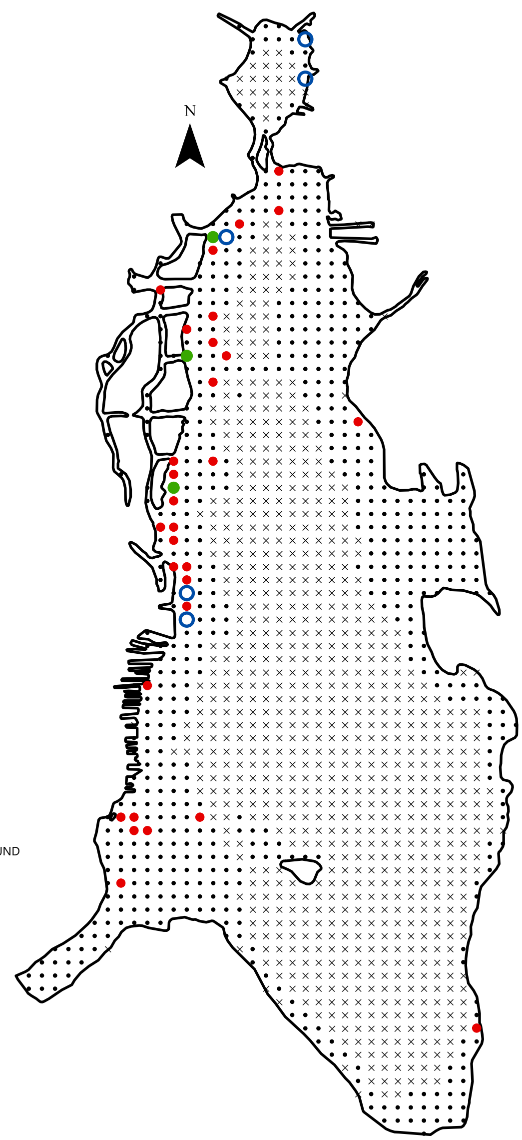
- Stout stems up to 2.0 m long, often branched
- Submerged leaves with nine to 19 veins (midvein prominent) on short stalks (up to 4.0 cm) or attached directly to the stem
- Floating leaves, if produced, elliptical, with 13 to 29 veins
- Often covered with calcium carbonate in hard water

Variable pondweed (*P. gramineus*) is similar to Illinois pondweed, but differs in having three to seven veins on submerged leaves

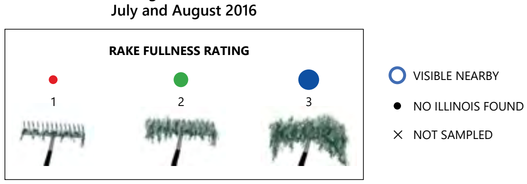
Ecology

- Lakes with clear water, shallow or deep, neutral or hard, over soft sediments
- Overwinters as rhizomes or remains green under the ice
- Provides food for waterfowl, muskrat, deer, and beaver
- Provides excellent habitat for fish and aquatic invertebrates

Credit: Flickr User Fernando Arcas



Nagawicka Lake
July and August 2016



Native

FLOATING-LEAF PONDWEED

Potamogeton natans

Credit: Wikimedia Commons User Stefan.lefnaer

Identifying Features

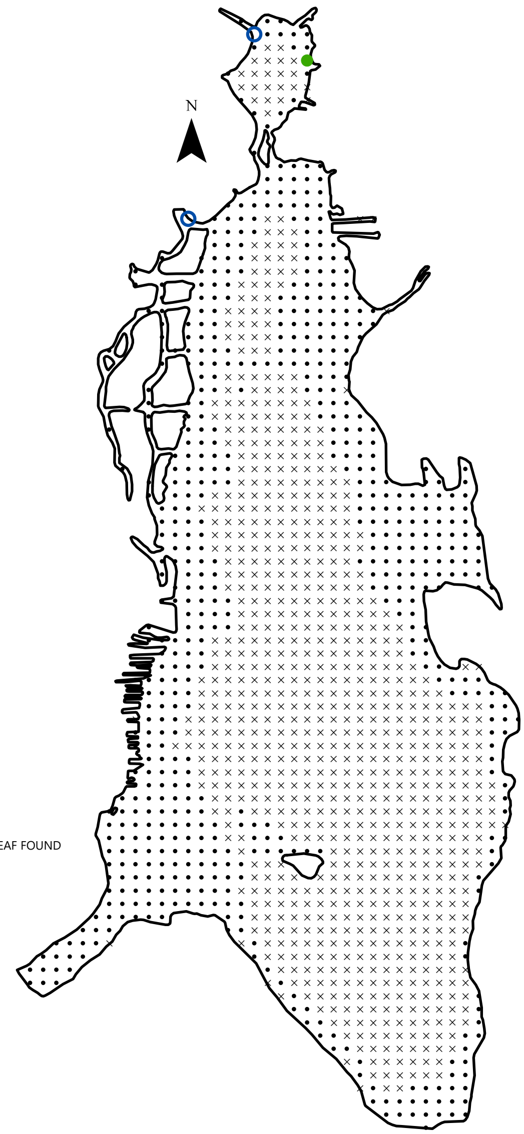
- Floating leaves (5.0 to 10 cm long) with heart-shaped bases and 17 to 37 veins
- Floating leaf stalks bent where they meet the leaf, causing the leaf to be held at roughly a 90-degree angle to the stalk
- Submersed leaves (1.0 to 2.0 mm wide) linear and stalk-like, with three to five veins

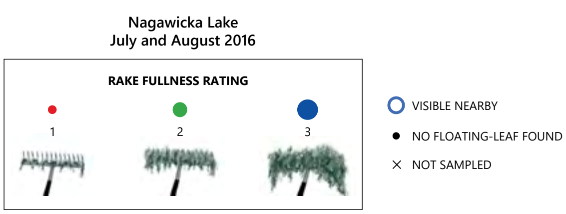
Floating-leaf pondweed is similar to Oakes' pondweed (*P. oakesianus*) and spotted pondweed (*P. pulcher*). Oake's pondweed is smaller, with floating leaves 2.5 to 6.0 cm long and submersed leaves 0.25 to 1.0 mm wide. Spotted pondweed differs in having small black spots on its stems and leaf stalks and lance-shaped submersed leaves with wavy margins

Ecology

- Usually in shallow waters (<2.5 m) over soft sediment
- Emerges in spring from buds formed along rhizomes
- Provides food for waterfowl, muskrat, beaver, and deer
- Holds fruit on stalks until late in the growing season, which provides valuable feeding opportunities for waterfowl
- Provides good fish habitat

Credit: Wikimedia Commons User Stefan.lefnaer

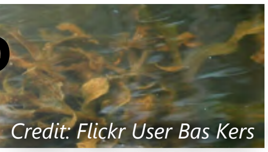




Native

WHITE-STEM PONDWEED

Potamogeton praelongus



Credit: Flickr User Bas Kers

Identifying Features

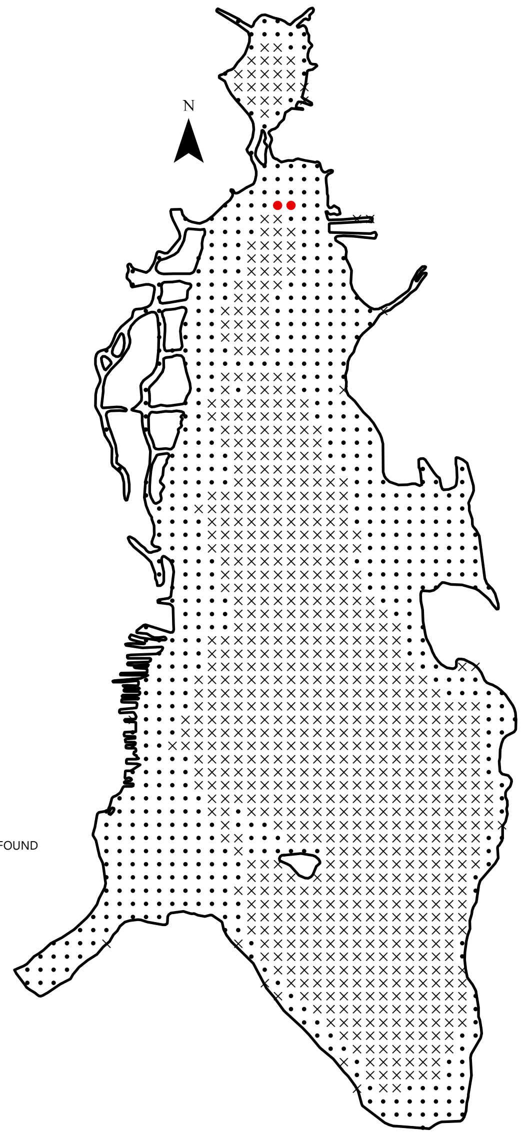
- Stems usually pale and zig-zagging
- Leaves clasping, alternate, with three to five prominent veins and 11 to 35 smaller ones, with boat-shaped tips that often split when pressed between fingers

White-stem pondweed is similar to clasping pondweed (*P. richardsonii*), but the leaves of clasping pondweed do not have boat-shaped tips that split when pressed

Ecology

- Found in clear lakes in water three to 12 feet deep over soft sediments
- "Indicator species" due to its sensitivity to water quality changes; its disappearance indicating degradation; requires more natural areas that receive little disturbance
- Sometimes remains evergreen beneath the ice
- Provides food for waterfowl, muskrat, beaver, and deer
- Provides habitat for trout and muskellunge

Credit: Flickr User fabelfroh



Native

CLASPING-LEAF PONDWEED
Potamogeton richardsonii

Credit: Flickr User Bas Kers

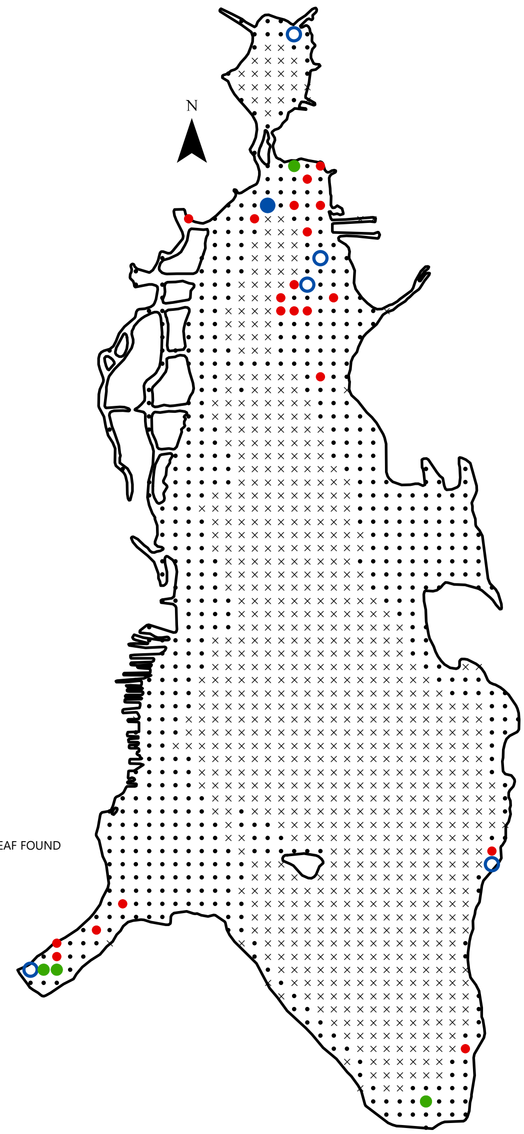
Identifying Features

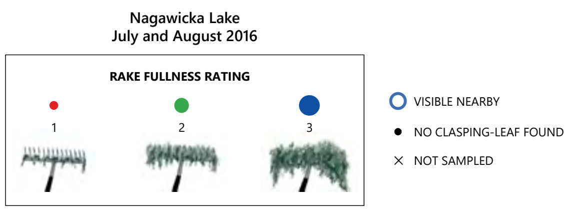
- Leaves alternating along and clasping the stem, with wavy edges, coming to a point at the tip, and often with three to five veins prominent among many more that are faintly visible
- Produces no floating leaves

Clasping pondweed is similar to white-stem pondweed (*P. praelongus*), but the latter has boat-shaped leaf tips that split when pressed between one's fingers. The exotic curly-leaf pondweed (*P. crispus*) may appear similar, but differs by having serrated leaf margins

Ecology

- In lakes and streams, shallow and deep, often in association with coontail
- Tolerant of disturbance
- Fruits a food source for waterfowl and plants browsed by muskrat, beaver, and deer
- Stems emerging from perennial rhizomes





Native

STIFF PONDWEED
Potamogeton strictifolius

Credit: Donald Cameron

Identifying Features

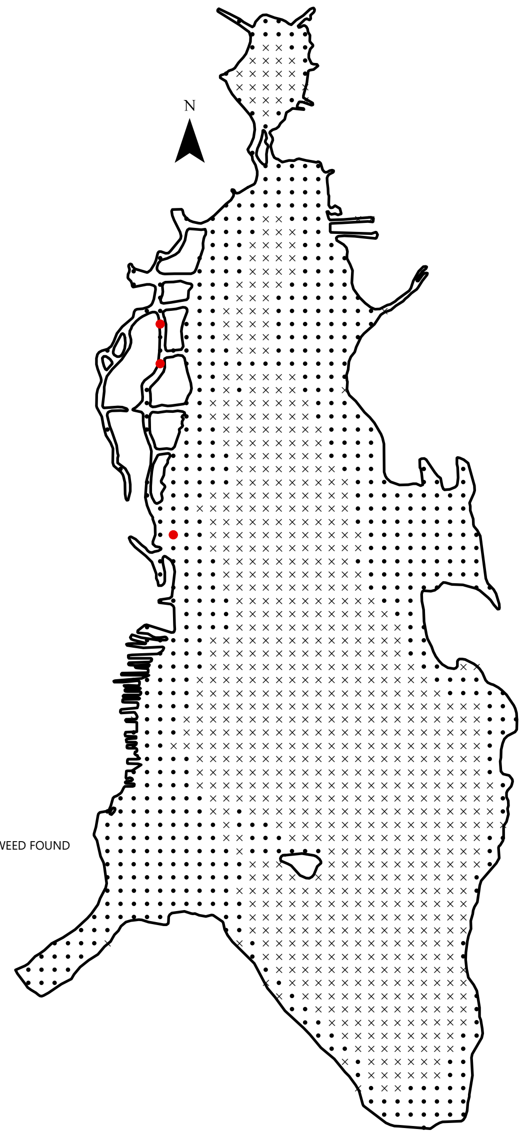
- Stems slender and flattened
- Leaves 2-6 cm long, with 3-5 veins, usually with paired glands at their bases, and sharply pointed or tipped with a fine bristle
- Stipule white, free from leaves, 7-15 mm and becoming fibrous by midsummer
- Fruits round, without ridges, and 2-3 mm long

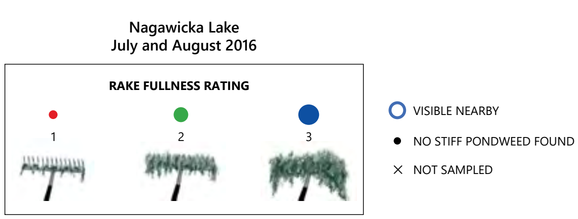
Stiff pondweed is similar to small pondweed (*P. pusillus*), but it differs in having glands at the bases of its leaves, flattened stems, and stipules that are not free from the stems.

Ecology

- Found in lakes, shallow and deep
- Produces overwintering buds known as turions
- Relatively uncommon in southeastern Wisconsin

Credit: Flickr User Brenton Butterfield





Native

FLAT-STEM PONDWEED

Potamogeton zosteriformis

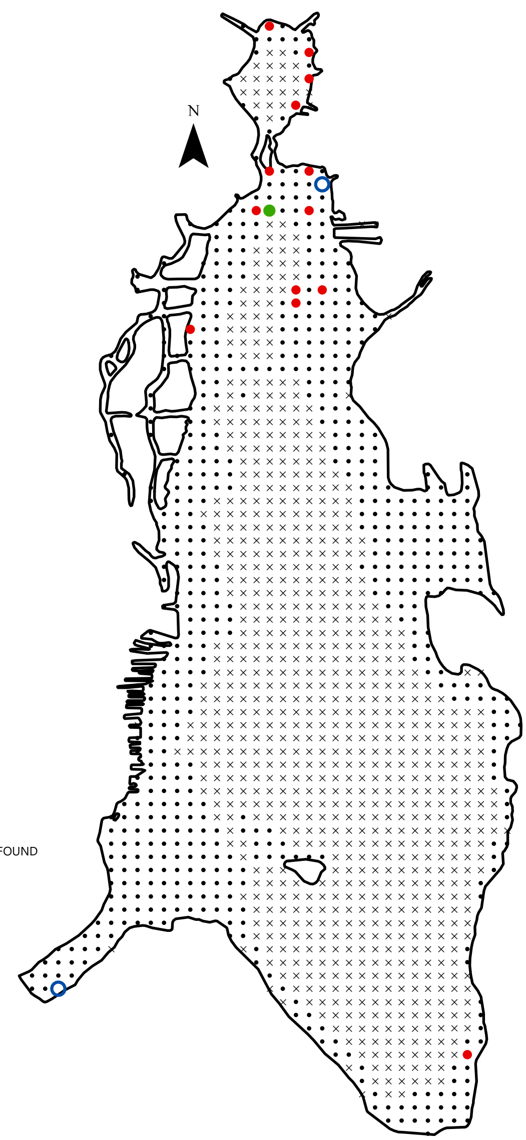
Identifying Features

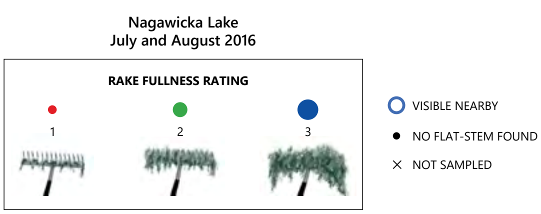
- Stems strongly flattened
- Leaves up to four to eight inches long, pointed, with a prominent midvein and many finer, parallel veins
- Stiff winter buds consisting of tightly packed ascending leaves

Flat-stem pondweed may be confused with yellow stargrass (*Heteranthera dubia*), but the leaves of yellow stargrass lack a prominent midvein.

Ecology

- Found at a variety of depths over soft sediment in lakes and streams
- Overwinters as rhizomes and winter buds
- Has antimicrobial properties
- Provides food for waterfowl, muskrat, beaver, and deer
- Provides cover for fish and aquatic invertebrates





Native

WHITE WATER CROWFOOT

Ranunculus aquatilis

Credit: Wikimedia Commons User Hans Hillewaert

Identifying Features

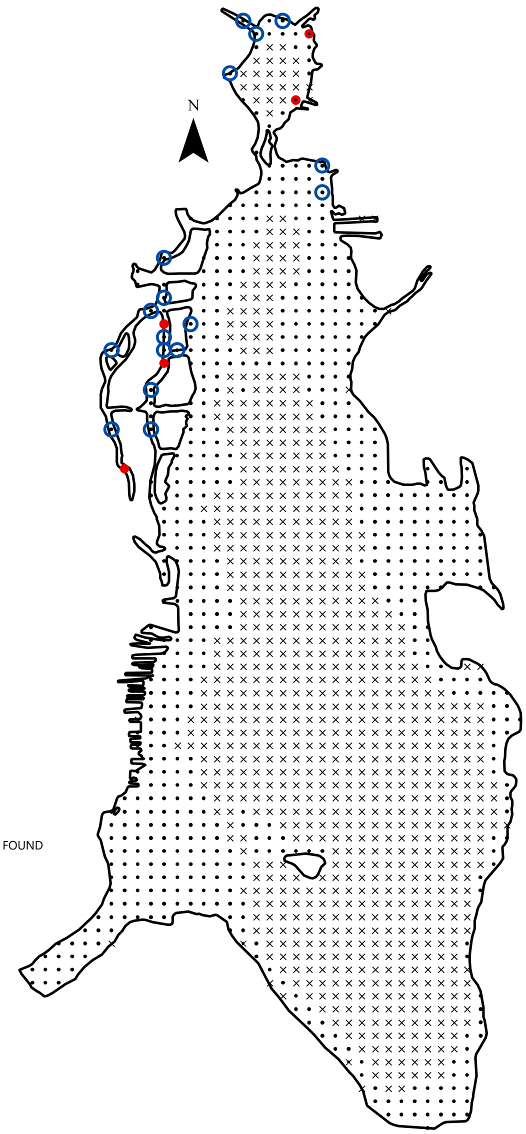
- Submersed leaves finely divided into thread-like sections, and arranged alternately along the stem
- Flowers white, with five petals
- May or may not produce floating leaves

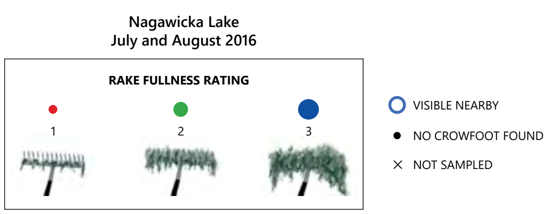
White water crowfoot is similar to other aquatic *Ranunculus* spp. However, the latter have yellow flowers and leaf divisions that are flat, rather than thread-like.

Ecology

- Shallow water in lakes or streams, often with high alkalinity
- Often forms dense patches near springs or sand bars
- Emerges from rhizomes in the spring
- Fruit and foliage consumed by waterfowl and upland birds alike
- Habitat for invertebrates that are food for fish like trout

Credit: Wikimedia Commons User Chmee2





Native

LARGE DUCKWEED

Spirodela polyrrhiza

Credit: Flickr User gailhampshire

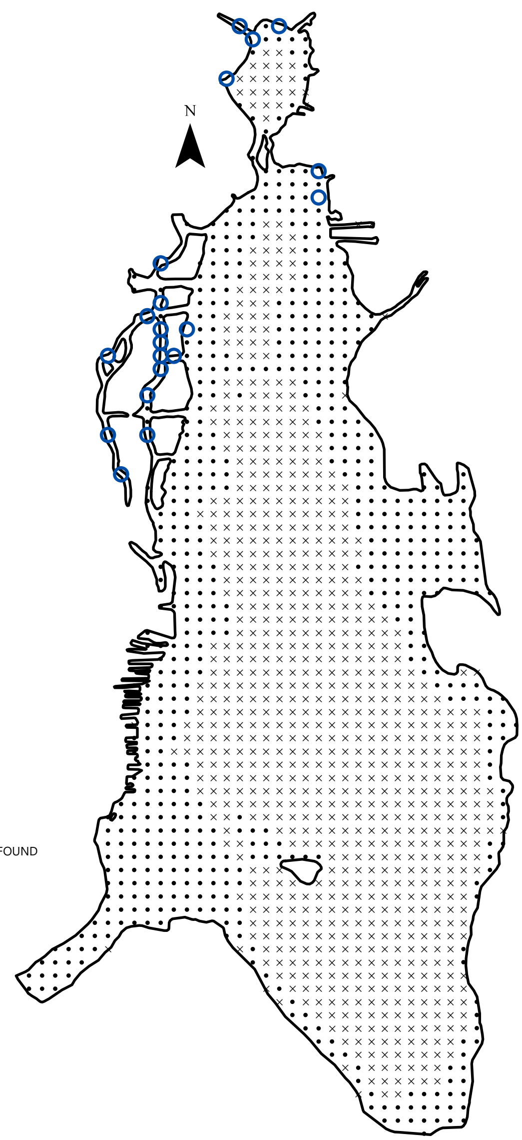
Identifying Features

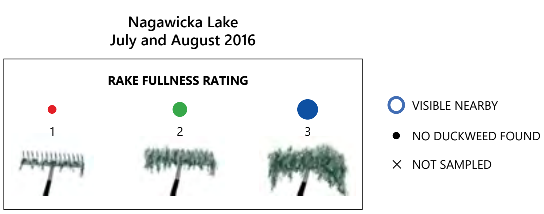
- Free-floating, nearly cicular fronds with 5 – 15 veins
- Often has several fronds in a cluster, with multiple roots
- Typically green above and a reddish-purple beneath

Ecology

- Found throughout Wisconsin
- Often found with duckweed species
- Not dependent on depth, sediment type, or water clarity
- Requires adequate nutrients in the water to sustain growth

Credit: Wikimedia Commons User Stefan.lefnaer





Native

SAGO PONDWEED

Stuckenia pectinata

Credit: Flickr User Christian Fischer

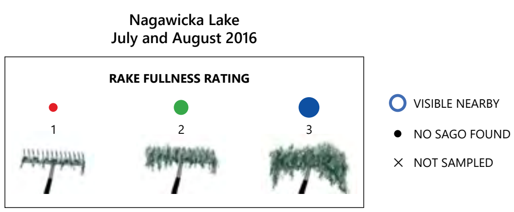
Identifying Features

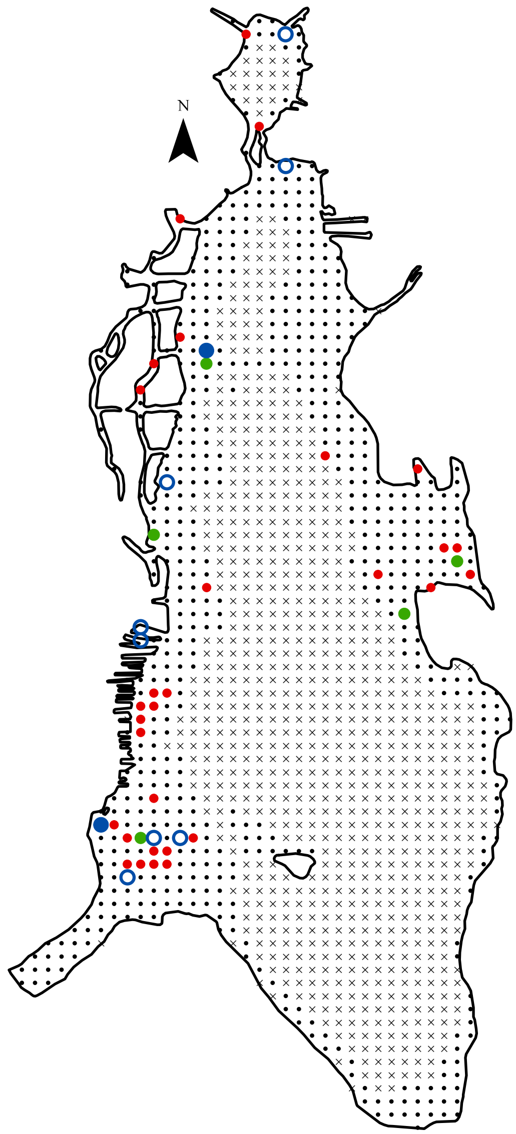
- Stems often *slightly zig-zagged* and forked multiple times, yielding a fan-like form
- Leaves one to four inches long, very thin, and ending in a sharp point
- Whorls of fruits spaced along the stem may appear as beads on a string

Ecology

- Lakes and streams
- Overwinters as rhizomes and starchy tubers
- Tolerates murky water and disturbed conditions
- Provides abundant fruits and tubers, which are an *important food for waterfowl*
- Provides habitat for juvenile fish

Credit: Flickr User Christian Fischer





Native

BLADDERWORTS

Utricularia spp.


Credit: Paul Skawinski

Identifying Features

- Flowers snapdragon-like, yellow or purple, held on stalks above the water surface
- *Producing bladders* (small air chambers on the stem) that capture prey and give buoyancy to the stem
- Stems either floating (due to air bladders) or anchored in the substrate; branches finely divided, if floating

Several similar bladderworts occur in southeastern Wisconsin

Ecology

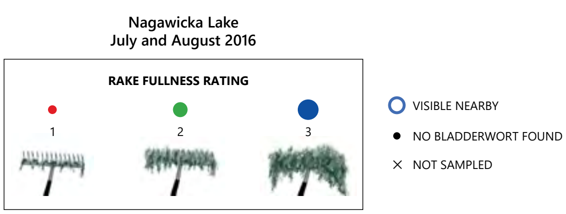
- Most species found in quiet shallows and along shores, but common bladderwort (*Utricularia vulgaris*) sometimes occurring in water several feet deep
- Provides forage and cover for a wide range of aquatic organisms
- Bladders capture and digest prey, including small invertebrates and protozoans

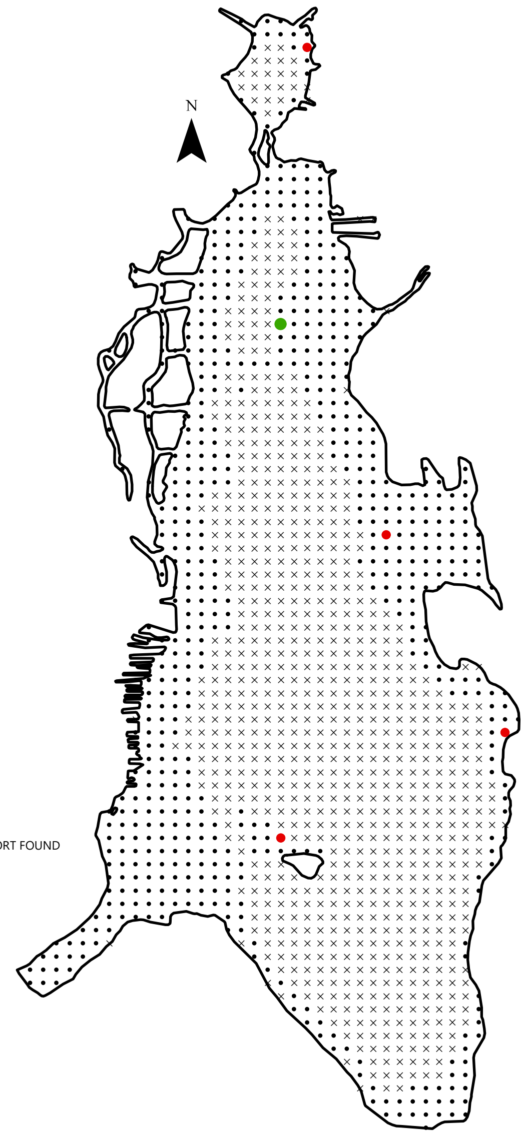

U. purpurea
Credit: Flickr User Doug McGrady


U. gibba
Credit: Wikimedia Common User Alex Popovkin


U. vulgaris
Credit: Wikimedia Commons User Michael Kurz


U. intermedia
Credit: Paul Skawinski





Native

WATER CELERY OR EELGRASS

Vallisneria americana

Credit: Wikimedia Commons User Fredlyfish4

Identifying Features

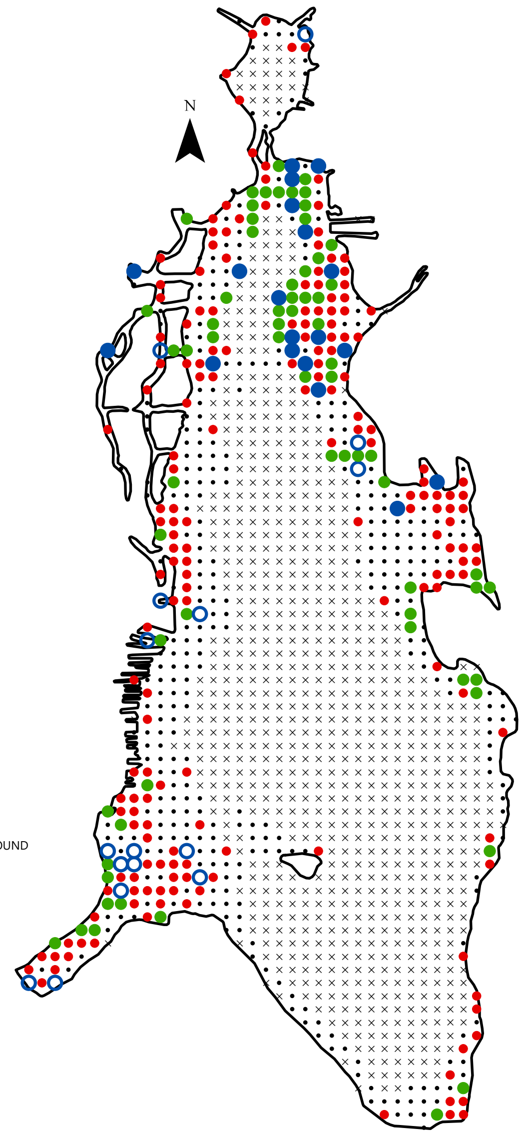
- Leaves ribbon-like, up to two meters long, with a prominent stripe down the middle, and emerging in clusters along creeping rhizomes
- Male and female flowers on separate plants, female flowers raised to the surface on spiral-coiled stalks

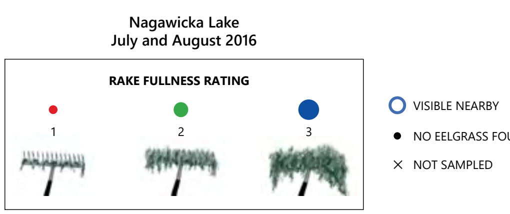
The foliage of eelgrass could be confused with the submersed leaves of bur-reeds (*Sparganium* spp.) or arrowheads (*Sagittaria* spp.), but the leaves of eelgrass are distinguished by their prominent middle stripe. The leaves of ribbon-leaf pondweed (*Potamogeton epihydrus*) are also similar to those of eelgrass, but the leaves of the former are alternately arranged along a stem rather than arising from the plant base

Ecology

- Firm substrates, shallow or deep, in lakes and streams
- Spreads by seed, by creeping rhizomes, and by offsets that break off and float to new locations in the fall
- All portions of the plant consumed by waterfowl; an especially important food source for Canvasback ducks
- Provides habitat for invertebrates and fish

Credit: Wikimedia Commons User Fredlyfish4





Native

COMMON, NORTHERN, AND BRAZILIAN WATERMEAL
Wolffia spp.


Credit: Wikimedia Commons User Stefan.lefnaer

Identifying Features

- Free-floating, green plant without roots, stems, or leaves, spherical or oblong
- Individual plants hardly larger than a pinhead
- Common Watermeal (*W. columbiana*) pale green, asymmetrical globes
- Northern Watermeal (*W. borealis*) flattened, ellipsoid, and dotted, with a pointed apex
- Brazilian Watermeal (*W. brasiliensis*) dotted, ellipsoid, with a rounded apex

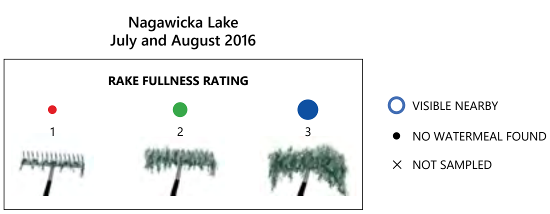
Ecology

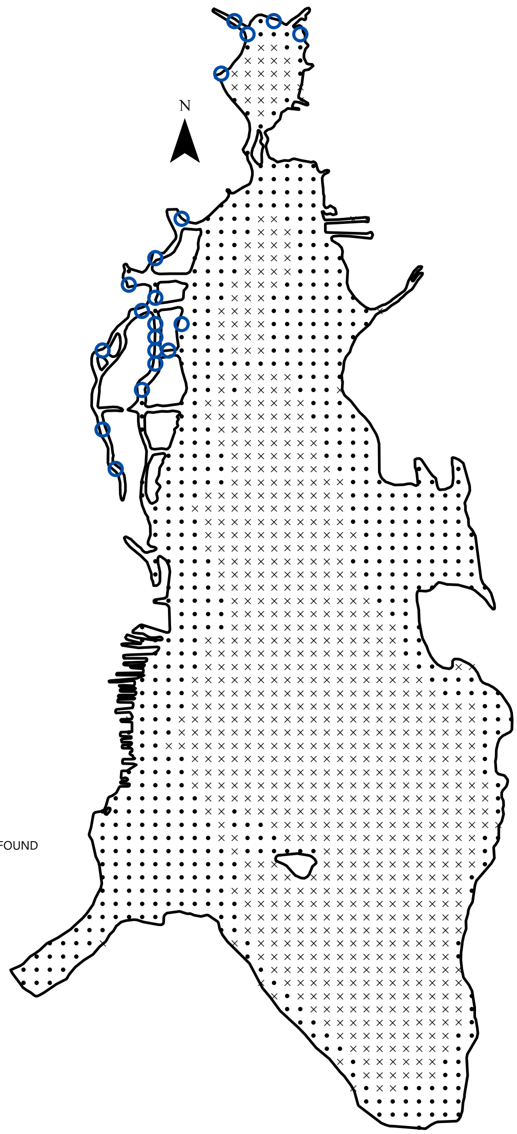
- Found throughout Wisconsin, except northern lakes and forest ecoregion
- Often found with duckweed species
- Not dependent on depth, sediment type, or water clarity
- Requires adequate nutrients in the water to sustain growth

Credit: Wikimedia Commons User Stefan.lefnaer

Credit: Flickr User Andrey Zharkikh

Credit: Flickr User Jim Stasz





NAGAWICKA LAKE WDNR SENSITIVE AREAS REPORT

APPENDIX D

LKS 0428.000

State of Wisconsin \ DEPARTMENT OF NATURAL RESOURCES

Carroll D. Besadny
Secretary

AQUATIC PLANT MANAGEMENT

SENSITIVE AREA ASSESSMENT SUMMARY

File Ref:

LAKE: NAGAWICKA COUNTY: WAUKESHA

DATE OF ASSESSMENT: JUNE 8, 1989 NUMBER OF SENSITIVE AREAS: 5

RESOURCE VALUE OF AREA #1

The area is commonly known as St. John's Bay. This area's most important function is that of spawning habitat for northern pike. The Department Fish Manager has determined through creel census that the northern pike population in the lake is diminishing, so it is important to protect and enhance northern's natural spawning habitat. St. John's Bay is the primary northern spawning area on the lake. The vegetation here is not very diverse but does provide nursery and feeding habitat year round for bass and panfish, as well as the northerns. It is important to end chemical treatments of this area by July 1 so that there will be sufficient regrowth of vegetation by spring for the northerns.

The banks in St. John's Bay provide muskrat with shelter. Raccoons, geese and mallards feed and rear their young in this area. The area just west of the island is primarily sand and gravel bottom and is a popular swimming area.

Vegetation in St. John's Bay helps stabilize the soft sediments. The plants also support an abundant amount of larger sized invertebrates. St. John's Bay also acts as a nutrient and sediment trap for the lake.

MANAGEMENT RECOMMENDATIONS FOR AREA #1

1. Mechanical treatment allowed with restrictions: Harvesting should end by July 1st and should be restricted to channels 25 feet from piers and extending out into open water. Minimal hand control allowed around piers & beaches.

2. Chemical treatment for Eurasian milfoil and purple loosestrife allowed only in navigational channels before July 1st.

3. None of the following inlake activities allowed:
   a. dredging
   b. filling
   c. boardwalks
   d. mechanical harvesting of vegetation in the area located northeast of St. John's Bay.

4. The following activities allowed with conditions:
   a. pea gravel/sand blankets in compliance with DNR provisions.
   b. aquascreen limited to area inside of navigational channel.

State of Wisconsin \ DEPARTMENT OF NATURAL RESOURCES

Carroll D. Besadny
Secretary

AQUATIC PLANT MANAGEMENT

File Ref:

SENSITIVE AREA ASSESSMENT SUMMARY

LAKE: NAGAWICKA COUNTY: WAUKESHA

DATE OF ASSESSMENT: JUNE 8, 1989 NUMBER OF SENSITIVE AREAS: 5

RESOURCE VALUE OF AREA #2

This area of Nagawicka Lake has an unusually large amount of shoreline, and is therefore extremely valuable to fish and wildlife. The shoreline gravel provides spawning beds for bass and is heavily used by bluegills. The area is also an important spawning area for northern pike. The vegetation is fairly diverse and includes pondweeds, Yellow & White Water Lilies, Milfoil, Chara, sedges and Arrow Head. This vegetation is not only an excellent habitat, but also provides a food base. The vegetation and stumps, deadfalls, and other woody vegetation are important nursery and feeding areas for fish.

The songbirds, shorebirds and waterfowl use the area for feeding, rearing their young, and nesting. Use during migration is especially high. Muskrat and raccoon also feed and rear their young here.

This area acts as a nutrient and sediment trap for the lake and the aquatic vegetation helps prevent shoreline erosion. Protection of the existing native plants is an important method of helping diminish invasions of Purple Loosestrife and Eurasian milfoil.

MANAGEMENT RECOMMENDATIONS FOR AREA #2

1. Chemical treatment not allowed.

2. Mechanical treatment restricted to center of channels.

3. None of the following inlake activities allowed:
   a. filling
   b. pea gravel/sand blanket

4. The following activities allowed with conditions:
   a. dredging restricted to 25 ft center of channel.
   b. private piers for riparians' use only.
   c. boardwalks allowed for educational purposes only.

State of Wisconsin \ DEPARTMENT OF NATURAL RESOURCES

Carroll D. Besadny
Secretary

AQUATIC PLANT MANAGEMENT

SENSITIVE AREA ASSESSMENT SUMMARY

LAKE: NAGAWICKA

File Ref:

COUNTY: WAUKESHA

DATE OF ASSESSMENT: JUNE 8, 1989 NUMBER OF SENSITIVE AREAS: 5

RESOURCE VALUE OF AREA #3

This area is called "the kettle" and is at the extreme north end of Nagawicka. The water depth drops off very quickly here to over 40 feet. Vegetation in this area includes Tamarack, sedges, cattails, pondweeds, water lilies, Purple Loosestrife and a variety of other emergent wetland vegetation.

The sedge and cattail fringe area is a good northern spawning area. The interconnecting channel between this area and the lake contains substantial amounts of tree stumps which provide cover, as well as a feeding and nursery area for bass and bluegill. The vegetation and substrate in the kettle provides nursery habitat, spawning beds, and feeding areas for bass, bluegill, crappie and northerns.

The kettle is used during migration by shorebirds, songbirds and waterfowl. Muskrat, opossum and raccoon feed and rear their young here. Wading birds feed in the area from spring until late fall.

The kettle acts as a nutrient and sediment trap for the lake and the aquatic vegetation helps prevent shoreline erosion. Protection of the existing native plants is an important method of helping diminish invasions of Purple Loosestrife and Eurasian milfoil.

MANAGEMENT RECOMMENDATIONS FOR AREA #3

1. Chemical treatment not allowed.

2. Mechanical treatment restricted to the existing NE channel to provide access to the kettle

3. None of the following inlake activities allowed:
   a. dredging, including stumps and vegetation
   b. pea gravel/sand blanket
   c. aquascreen
   d. filling

4. The following activities allowed with conditions:
   a. private piers for riparians' use only.
   b. boardwalks for educational purposes.

State of Wisconsin \ DEPARTMENT OF NATURAL RESOURCES

Carroll D. Besadny
Secretary

AQUATIC PLANT MANAGEMENT

SENSITIVE AREA ASSESSMENT SUMMARY

File Ref:

LAKE: NAGAWICKA COUNTY: WAUKESHA

DATE OF ASSESSMENT: JUNE 8, 1989 NUMBER OF SENSITIVE AREAS: 5

RESOURCE VALUE OF AREA #4

The wetland area, also known as Charlie's pond, is regulated by the Army Corp of Engineers, the City of Delafield, and the Department of Natural Resources. This is an extremely valuable wetland complex which drains the south end of Nagawicka Lake. The wetland acts as a sediment and nutrient trap and the aquatic vegetation helps prevent shoreline erosion.

Although the water is rather shallow most of the year, the wetland maintains a small population of most fish species that are found in Nagawicka Lake. The Department's Fish Manager uses the excellent spawning habitat in the wetland to propagate northern pike. The area is also a very good nursery area for most pan fish.

The wetland is considered a quality feeding area for wading birds, especially during migration. Migrating song birds frequent the area to nest, feed and rear their young. Muskrats, raccoons and waterfowl also frequent the area. Protection of the existing native plants is an important method of helping diminish invasions of Purple Loosestrife and Eurasian milfoil.

MANAGEMENT RECOMMENDATIONS FOR AREA #4

1. Chemical treatment not allowed.

2. Mechanical treatment limited to minimal hand control by piers.

3. None of the following inlake activities allowed:
   a. dredging
   b. pea gravel/sand blanket
   c. filling

4. The following activities allowed with conditions:
   a. aquascreen can be used, but only on riparians immediate shoreline-remove annually.
   b. piers for riparians' use only.
   c. boardwalks for educational and aesthetic purposes only, and not to provide boat access.

State of Wisconsin \ DEPARTMENT OF NATURAL RESOURCES

Carroll D. Besadny
Secretary

AQUATIC PLANT MANAGEMENT

SENSITIVE AREA ASSESSMENT SUMMARY File Ref:

LAKE: NAGAWICKA COUNTY: WAUKESHA

DATE OF ASSESSMENT: JUNE 8, 1989 NUMBER OF SENSITIVE AREAS: 5

RESOURCE VALUE OF AREA #5

This area is the Bark River area leading into Nagawicka Lake. It provides an estuary habitat that is used by northerns and a variety of wildlife. The river provides white suckers with very good gravel areas which are used for spawning.

The river supports a variety of plant species. Emergent plants include cattails, sedges, Purple Loosestrife. Submergent plants include milfoil, pondweeds, and Yellow Water Lily.

Waterfowl nest and feed in the area, and it provides excellent habitat during migration. Muskrat and raccoon feed in the area.

This river acts as a nutrient and sediment trap for the lake and the aquatic vegetation helps prevent shoreline erosion. Protection of the existing native plants is an important method of helping diminish invasions of Purple Loosestrife and Eurasian Milfoil.

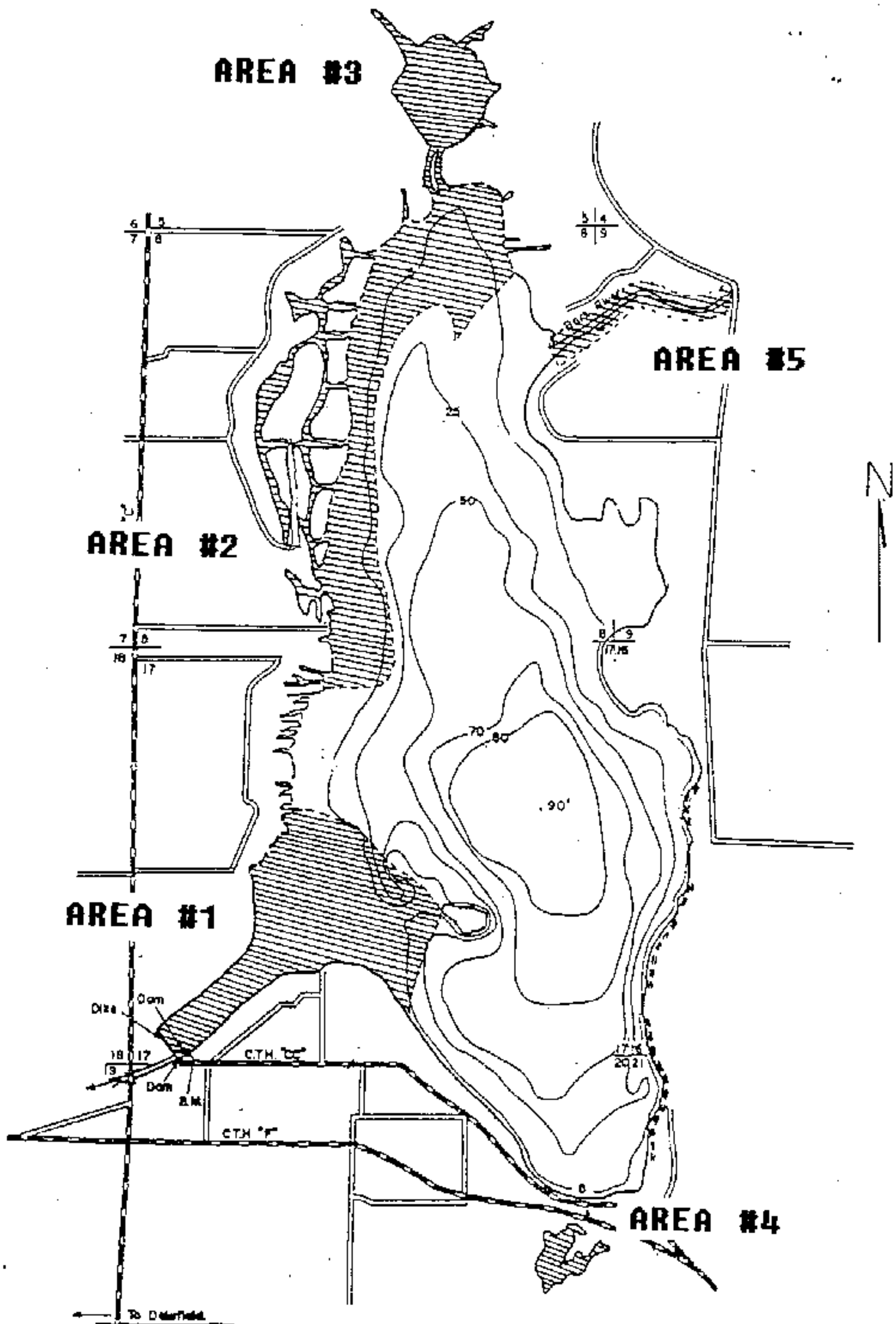
MANAGEMENT RECOMMENDATIONS FOR AREA #5

1. Chemical treatment not allowed.

2. Mechanical treatment limited to hand control for navigation.

3. None of the following inlake activities allowed:
   a. dredging
   b. pea gravel/sand blanket
   c. aquascreen
   d. boardwalks

4. The following activities allowed with conditions:
   a. private piers for riparians' use only.

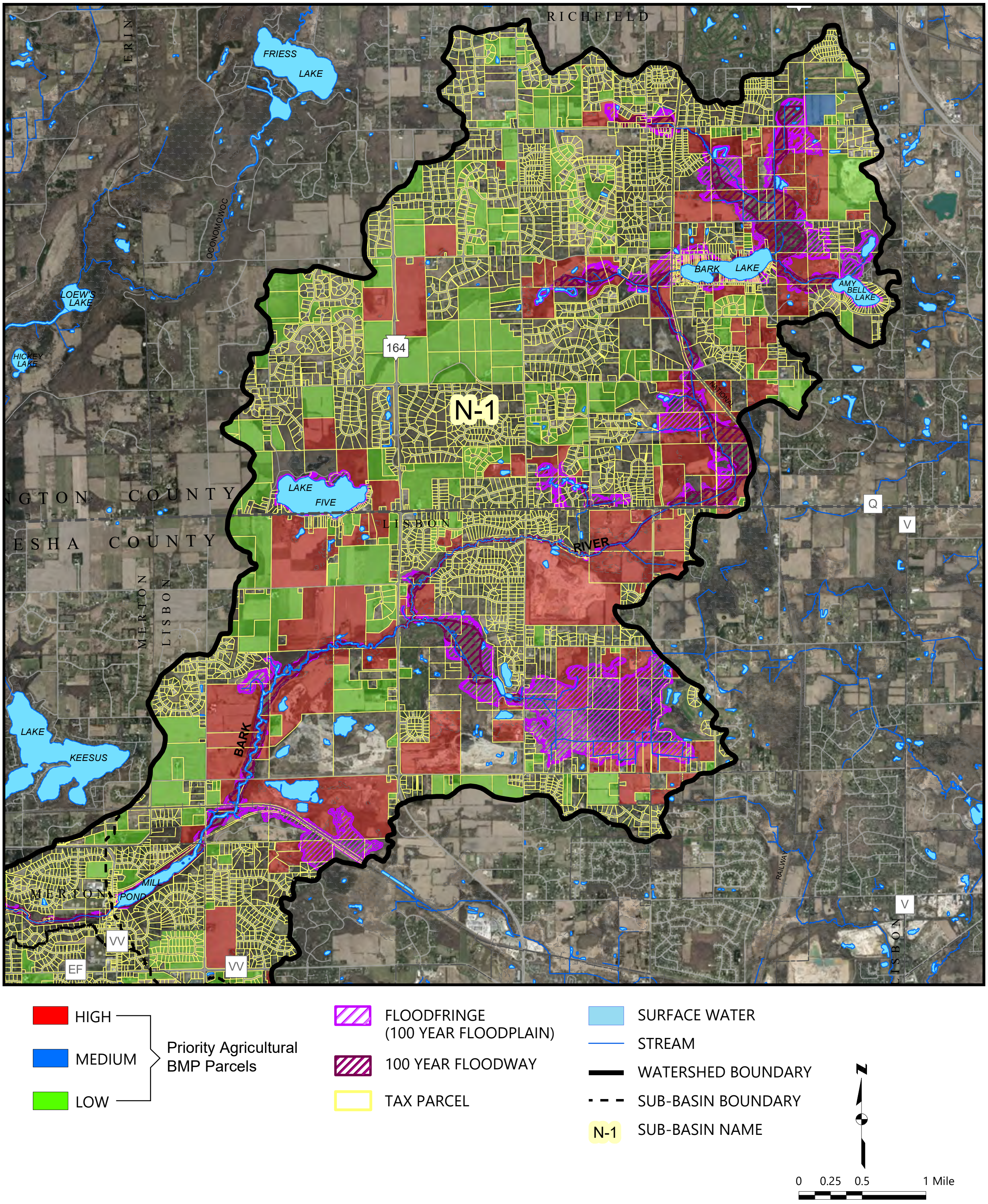


NAGAWICKA LAKE
SENSITIVE AREAS

PRIORITY PARCELS FOR AGRICULTURAL BEST MANAGEMENT PRACTICES

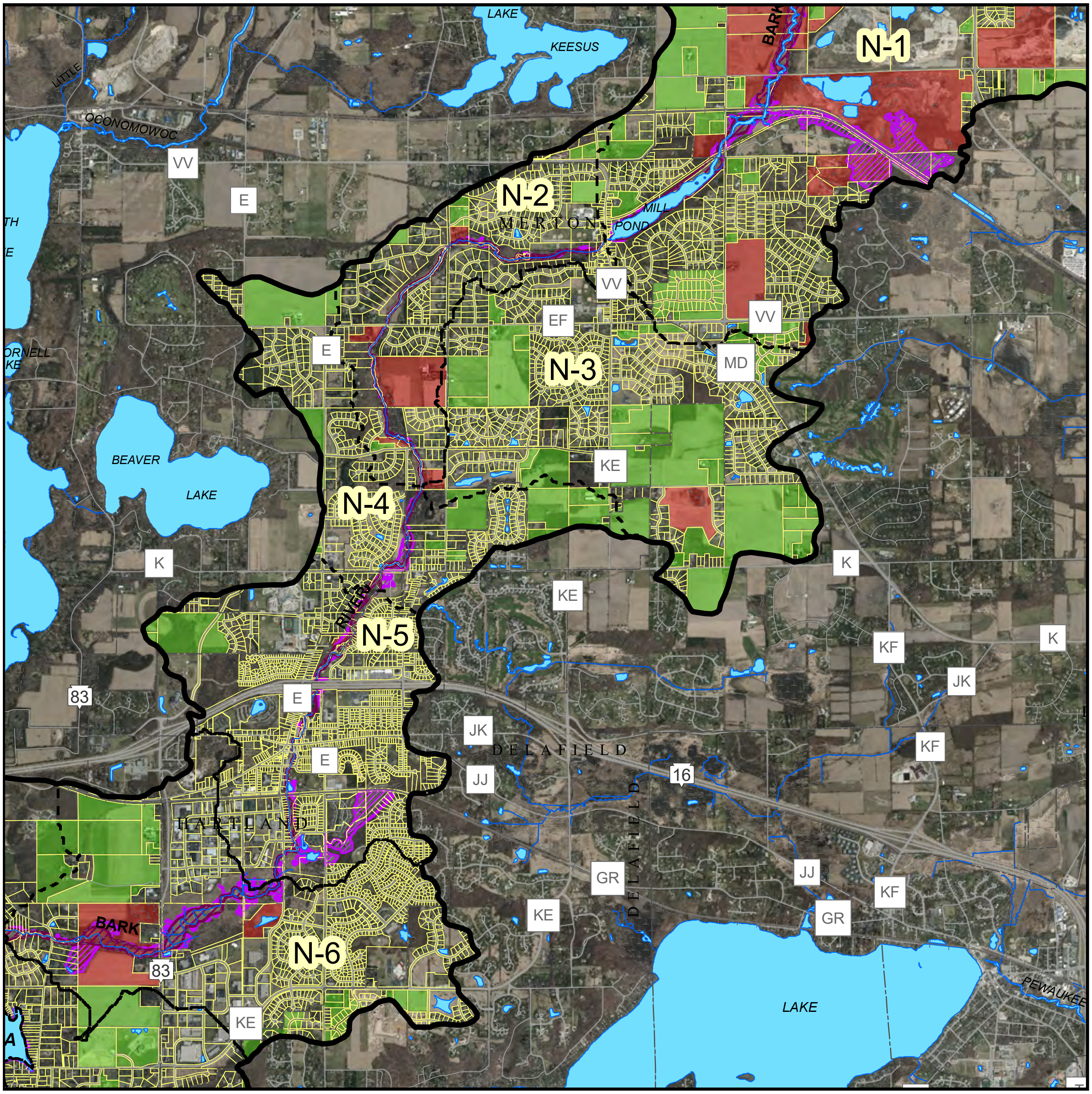
APPENDIX E

Map E.1
Prioritization Among Parcels for Implementation of Agricultural Best Management Practices (BMPs) Among Sub-Basin N-1 Within the Nagawicka Lake Watershed:2015



Source: USGS and SEWRPC

Map E.2
Prioritization Among Parcels for Implementation of Agricultural Best Management Practices (BMPs) Among Sub-Basins N-2 Through N-5 Within the Nagawicka Lake Watershed: 2015



HIGH
MEDIUM
LOW
Priority Agricultural BMP Parcels

FLOODFRINGE (100 YEAR FLOODPLAIN)
100 YEAR FLOODWAY
TAX PARCEL

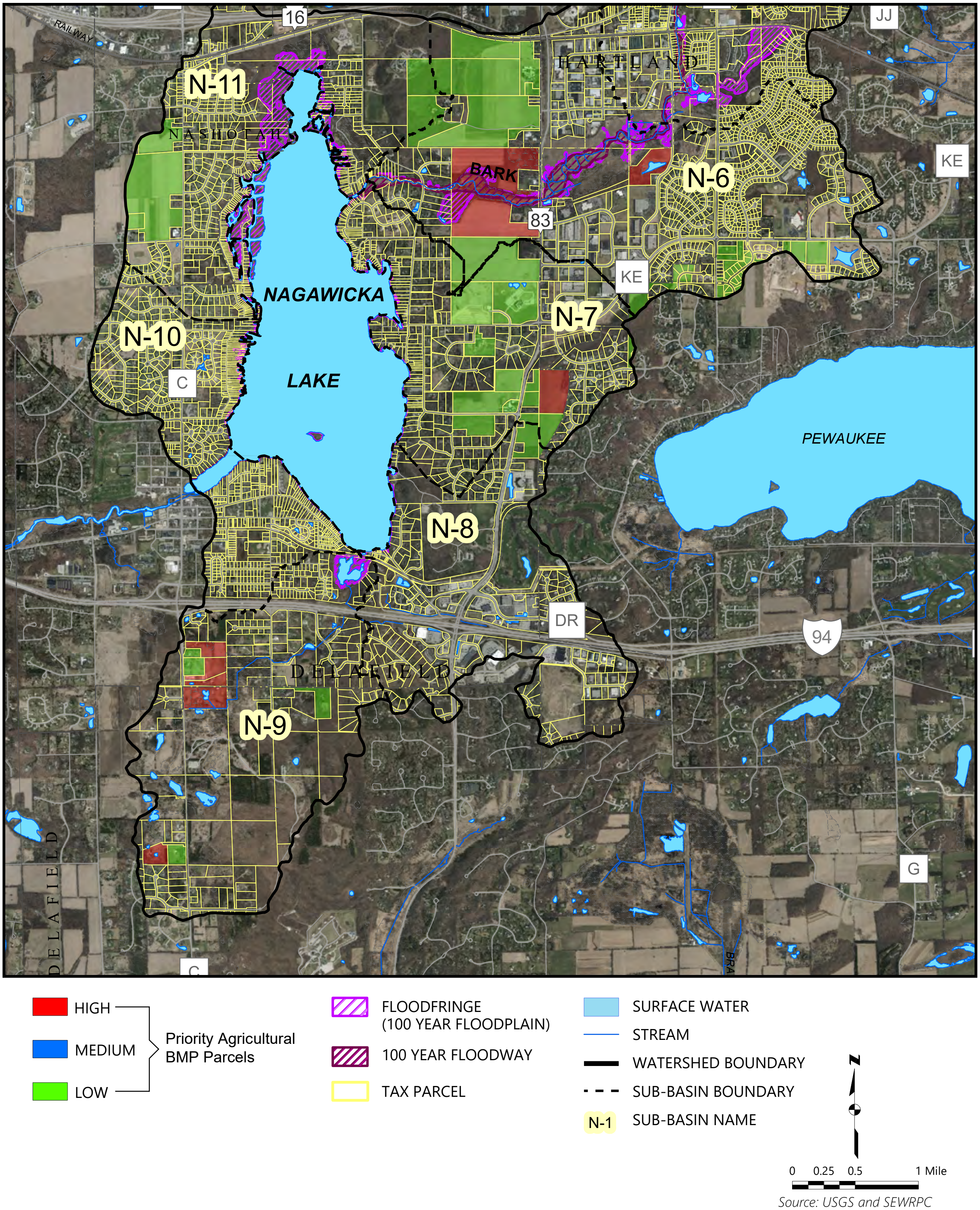
SURFACE WATER
STREAM
WATERSHED BOUNDARY
SUB-BASIN BOUNDARY
N-1 SUB-BASIN NAME

N

0 0.25 0.5 1 Mile

Source: USGS and SEWRPC

Map E.3
Prioritization Among Parcels For Implementation of Agricultural Best Management Practices (BMPs) Among Sub-Basins N-6 Through N-11 Within the Nagawicka Lake Watershed: 2015

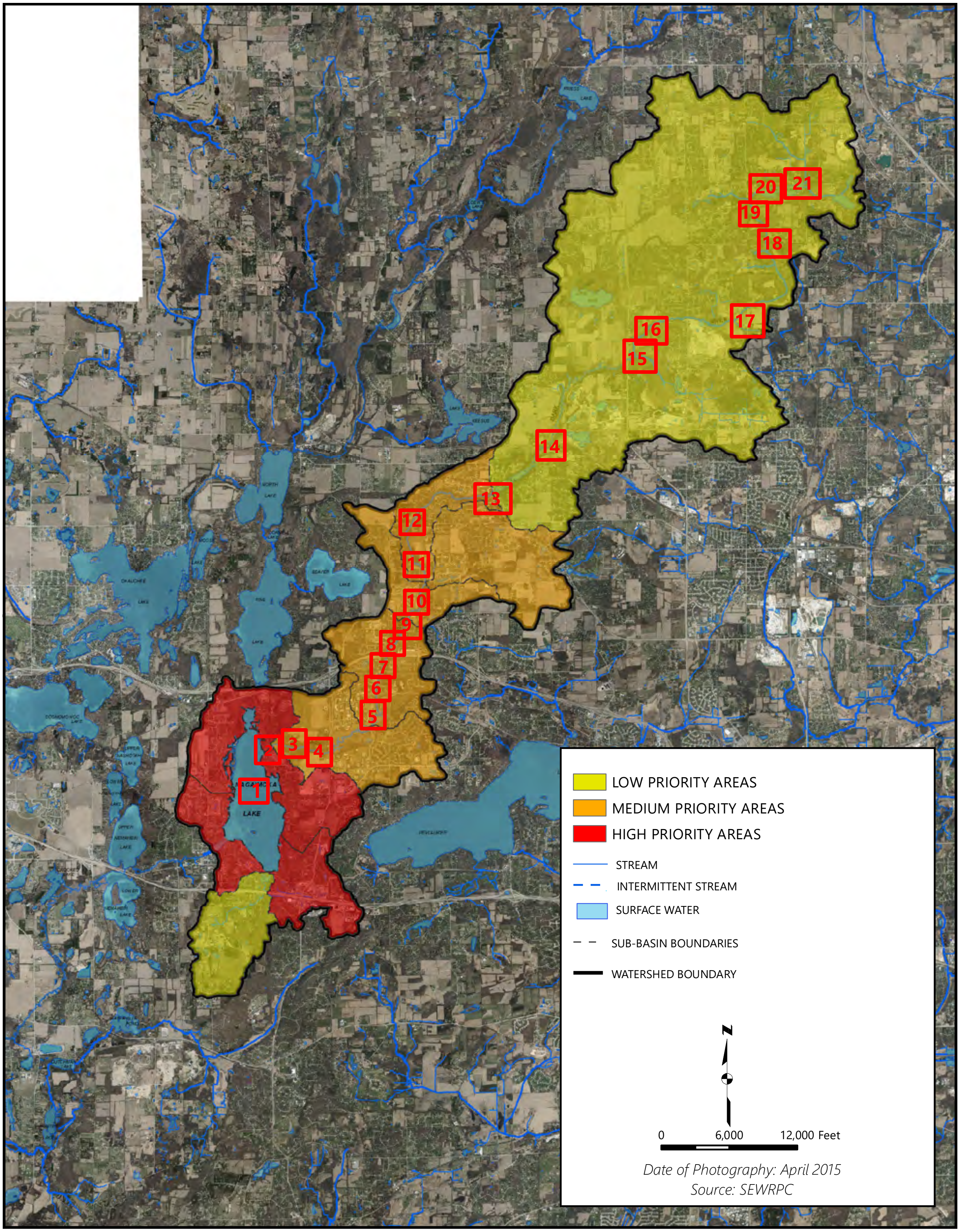


Source: USGS and SEWRPC

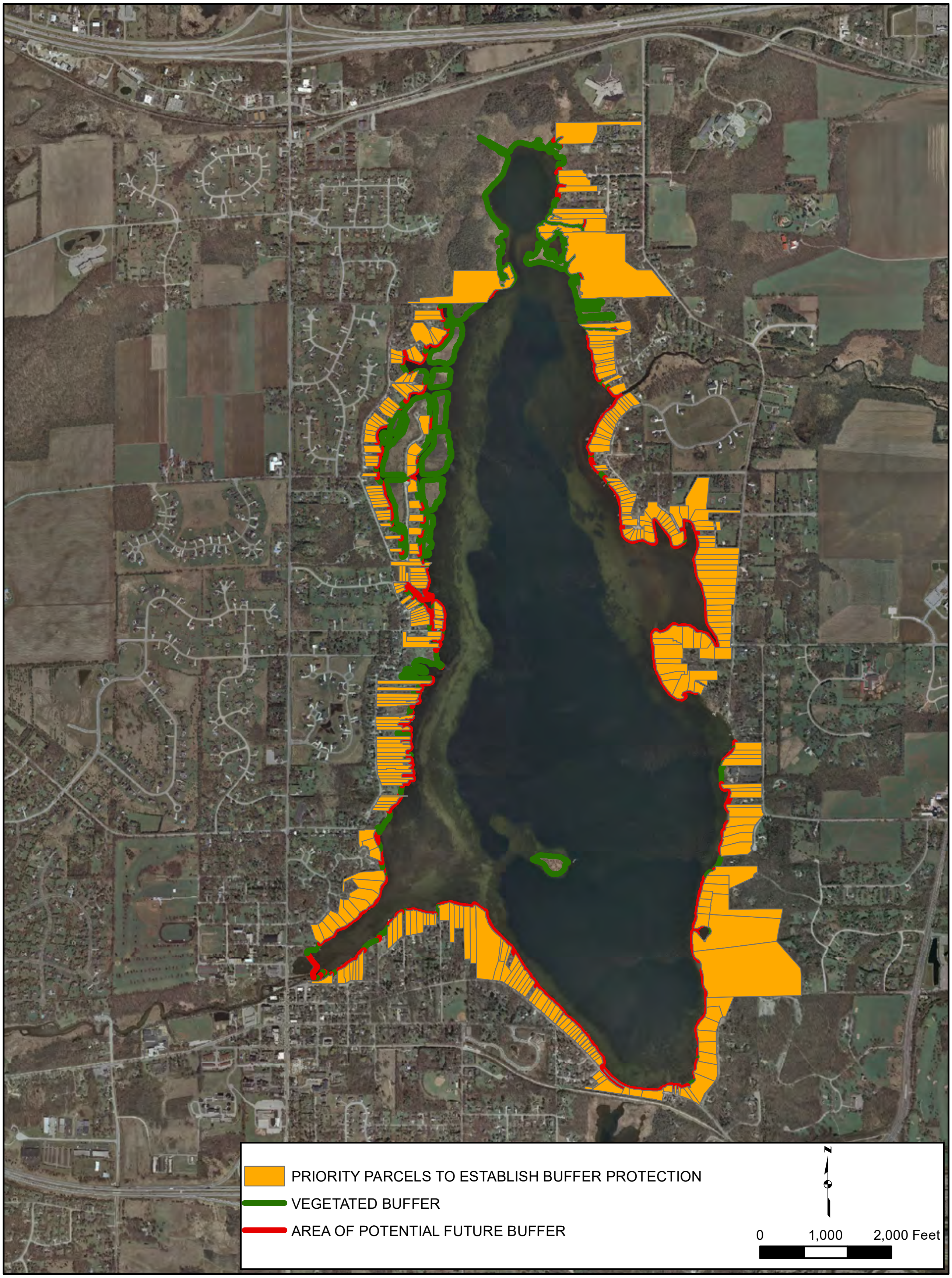
APPENDIX F

PRIORITY BUFFER AREAS

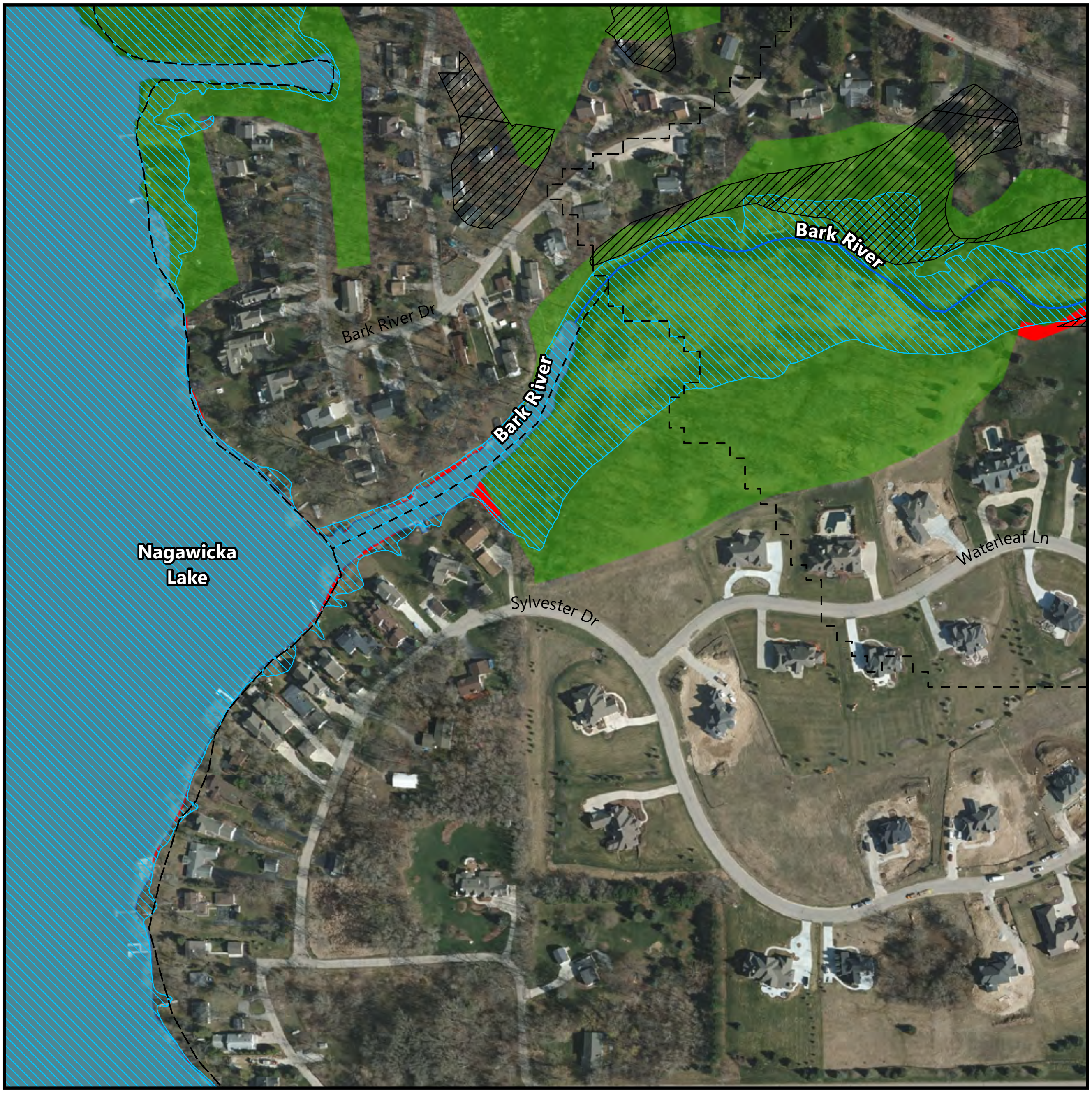
Map F.1
Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



Map F.1 (Inset 1)
High Priority Buffer Areas



Map F.1 (Inset 2)
High Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



EXISTING RIPARIAN BUFFER:
-PROTECT THESE HIGHEST QUALITY REMAINING HABITAT AREAS.

75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH:
-HIGH PRIORITY TO PROTECT WATER QUALITY AND REDUCE POLLUTANT LOADS.

STREAM

INTERMITTENT STREAM

SURFACE WATER

POTENTIALLY RESTORABLE WETLANDS:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

ONE-PERCENT-ANNUAL-PROBABILITY FLOODPLAIN: FEMA 2015:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

SUB-BASIN BOUNDARIES

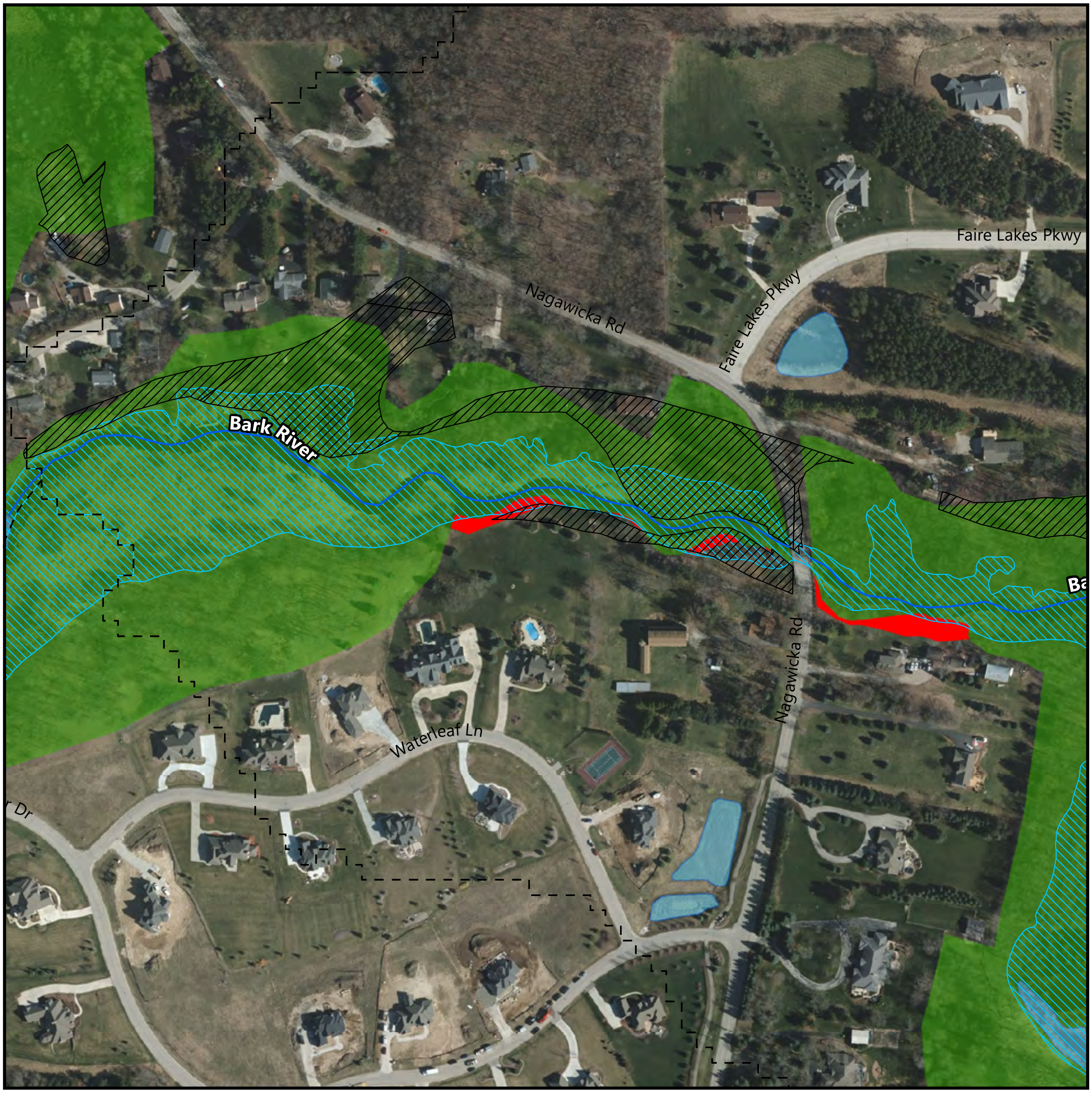
WATERSHED BOUNDARY

N

0 150 300 Feet

Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 3)
Medium Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



EXISTING RIPARIAN BUFFER:
-PROTECT THESE HIGHEST QUALITY REMAINING HABITAT AREAS.

75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH:
-HIGH PRIORITY TO PROTECT WATER QUALITY AND REDUCE POLLUTANT LOADS.

POTENTIALLY RESTORABLE WETLANDS:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

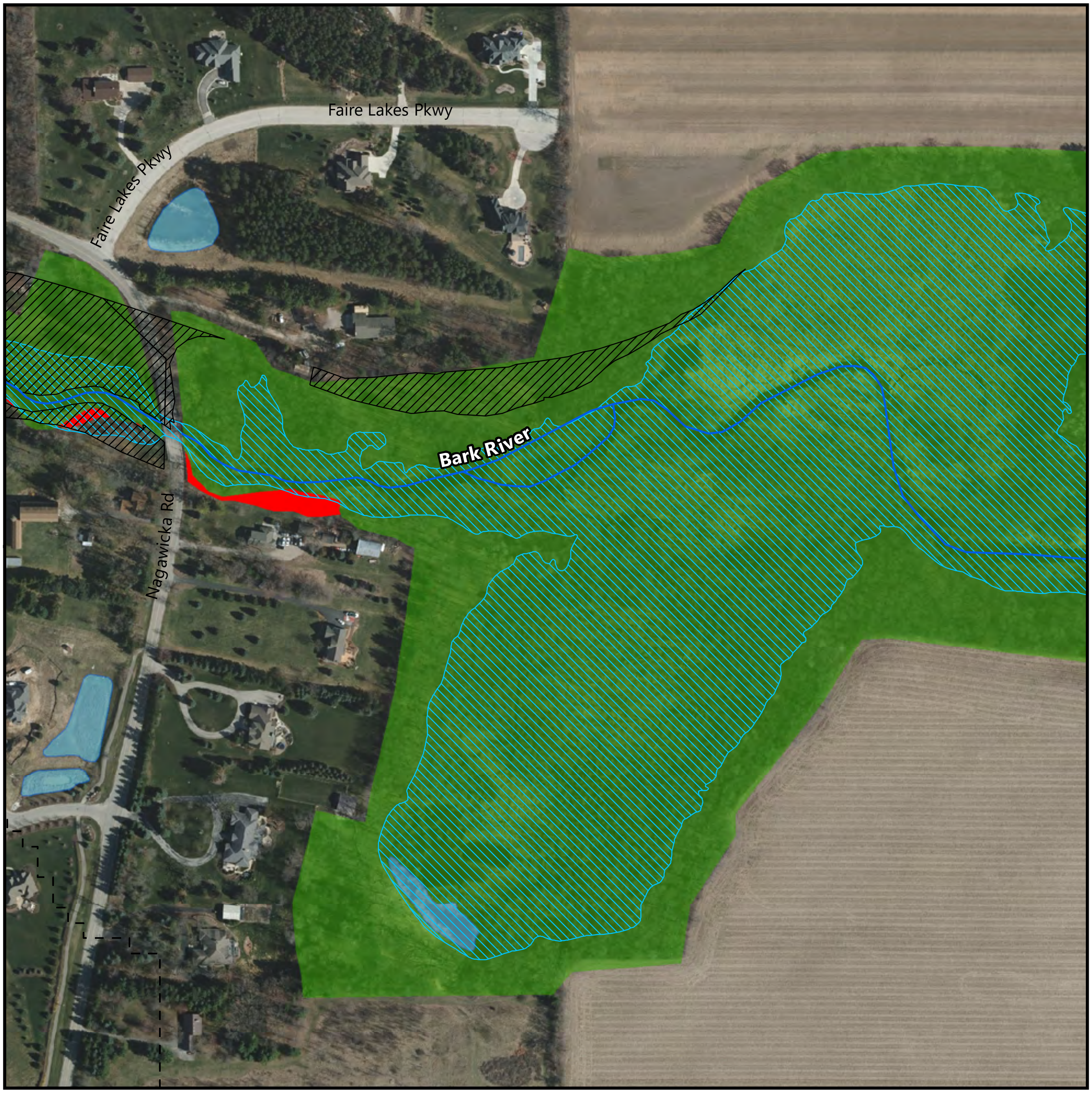
ONE-PERCENT-ANNUAL-PROBABILITY FLOODPLAIN: FEMA 2015:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

STREAM
INTERMITTENT STREAM
SURFACE WATER
SUB-BASIN BOUNDARIES
WATERSHED BOUNDARY

N
0 150 300 Feet

Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 4)
Medium Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



EXISTING RIPARIAN BUFFER:
-PROTECT THESE HIGHEST QUALITY REMAINING HABITAT AREAS.

75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH:
-HIGH PRIORITY TO PROTECT WATER QUALITY AND REDUCE POLLUTANT LOADS.

POTENTIALLY RESTORABLE WETLANDS:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

ONE-PERCENT-ANNUAL-PROBABILITY FLOODPLAIN: FEMA 2015:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

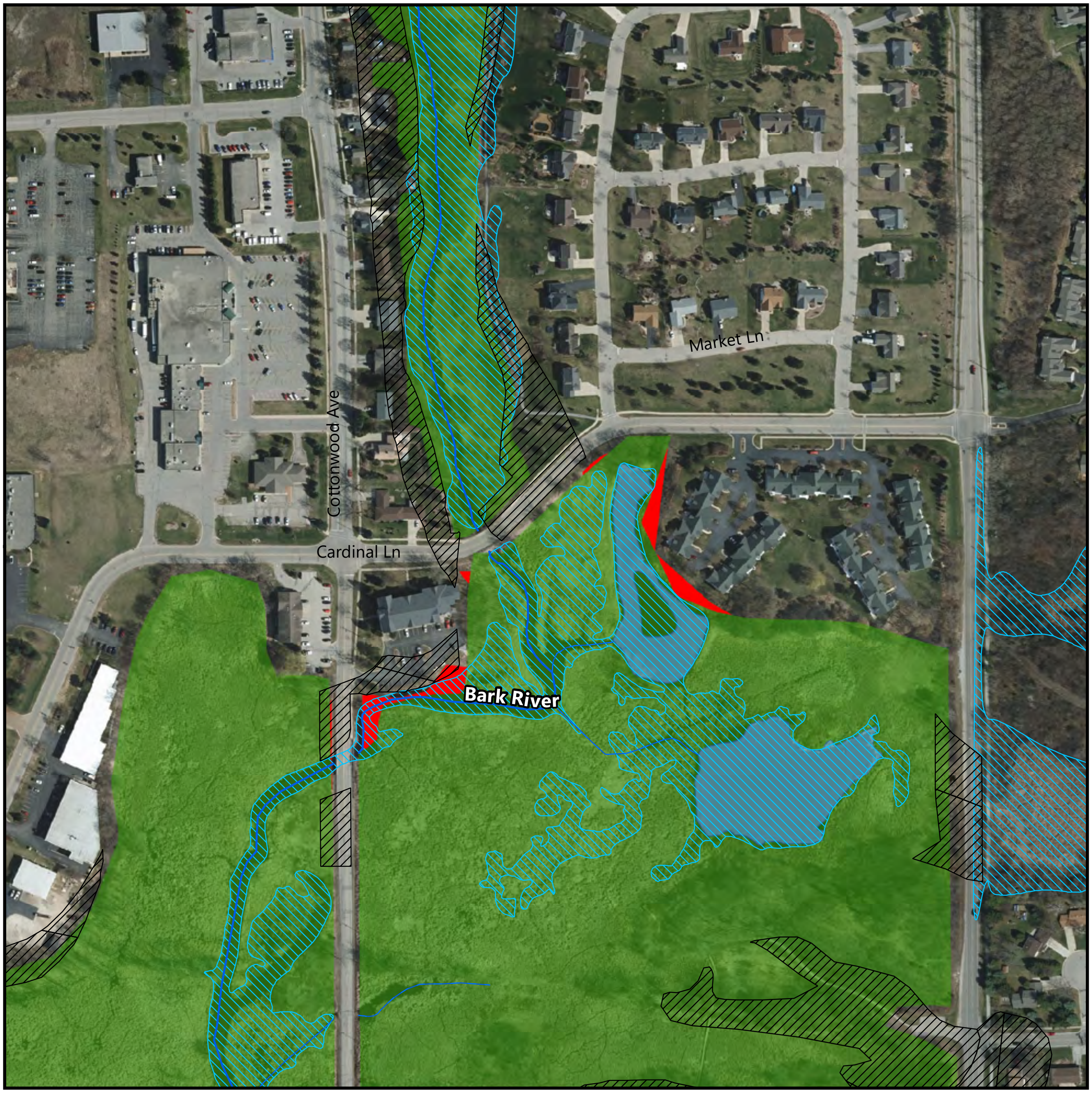
STREAM
INTERMITTENT STREAM
SURFACE WATER

SUB-BASIN BOUNDARIES
WATERSHED BOUNDARY

N
0 150 300 Feet

Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 5)
Medium Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



EXISTING RIPARIAN BUFFER:
-PROTECT THESE HIGHEST QUALITY REMAINING HABITAT AREAS.

75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH:
-HIGH PRIORITY TO PROTECT WATER QUALITY AND REDUCE POLLUTANT LOADS.

STREAM

INTERMITTENT STREAM

SURFACE WATER

POTENTIALLY RESTORABLE WETLANDS:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

ONE-PERCENT-ANNUAL-PROBABILITY FLOODPLAIN: FEMA 2015:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

SUB-BASIN BOUNDARIES

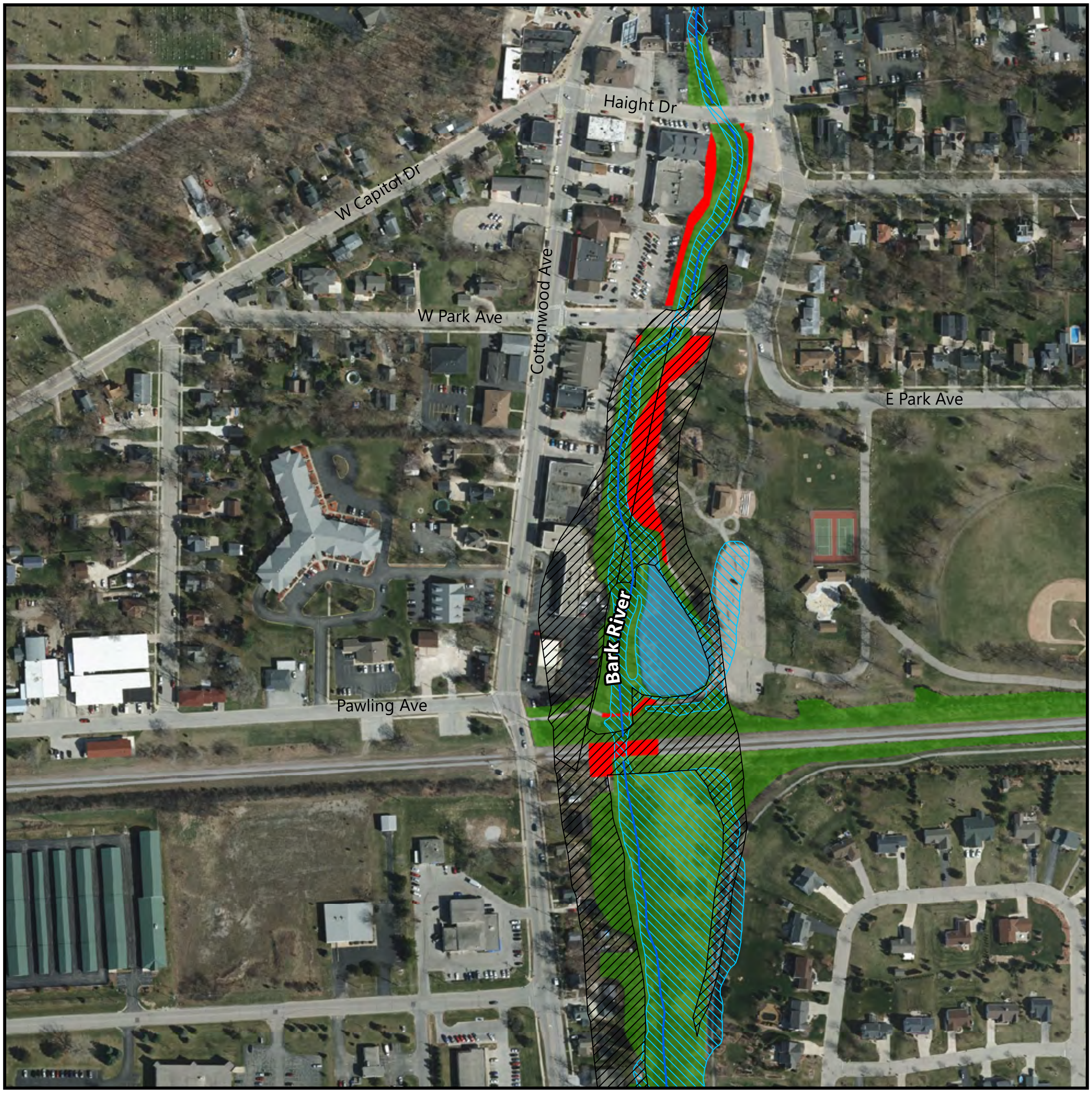
WATERSHED BOUNDARY

N

0 150 300 Feet

Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 6)
Medium Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



EXISTING RIPARIAN BUFFER:
-PROTECT THESE HIGHEST QUALITY REMAINING HABITAT AREAS.

75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH:
-HIGH PRIORITY TO PROTECT WATER QUALITY AND REDUCE POLLUTANT LOADS.

STREAM

INTERMITTENT STREAM

SURFACE WATER

POTENTIALLY RESTORABLE WETLANDS:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

ONE-PERCENT-ANNUAL-PROBABILITY FLOODPLAIN: FEMA 2015:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

SUB-BASIN BOUNDARIES

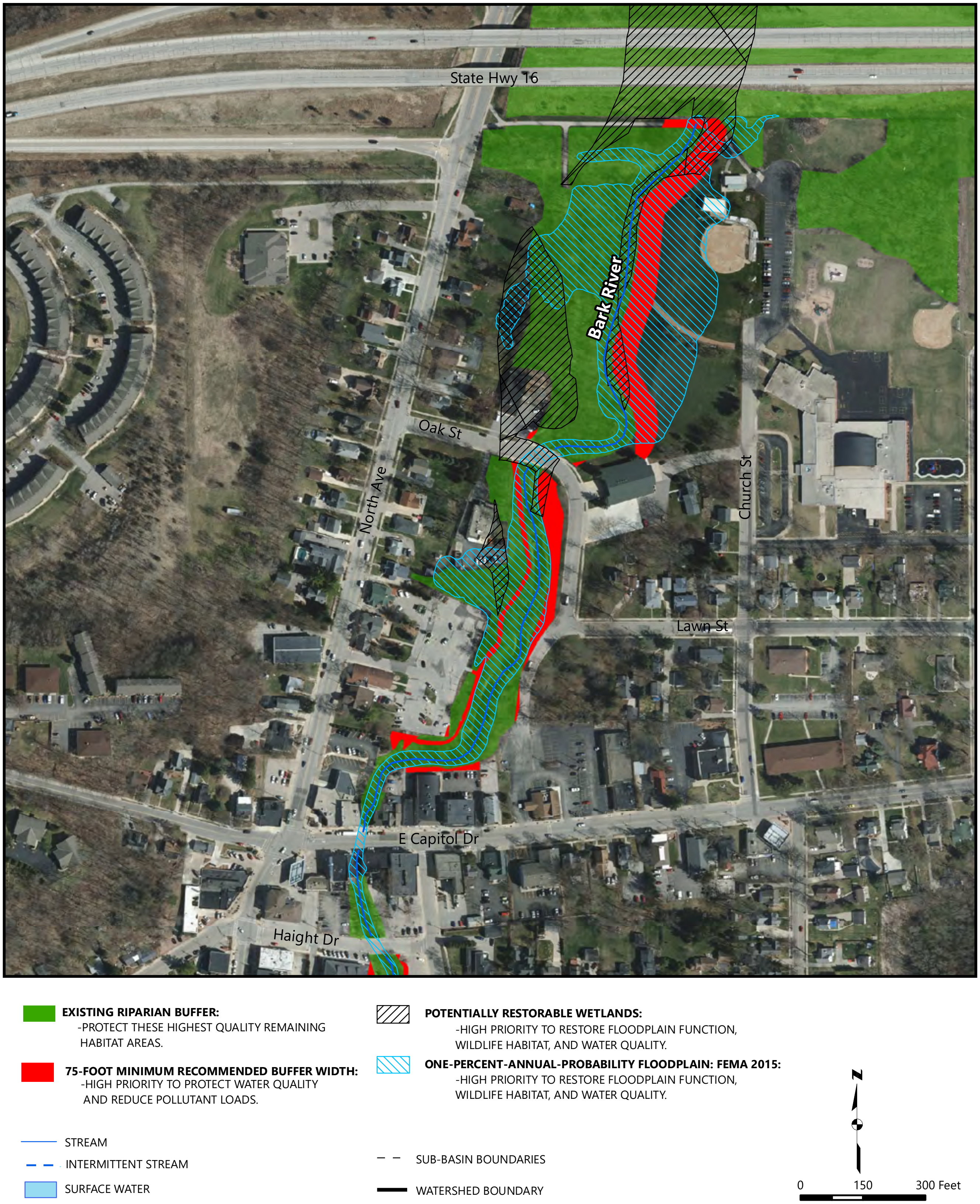
WATERSHED BOUNDARY

N

0 150 300 Feet

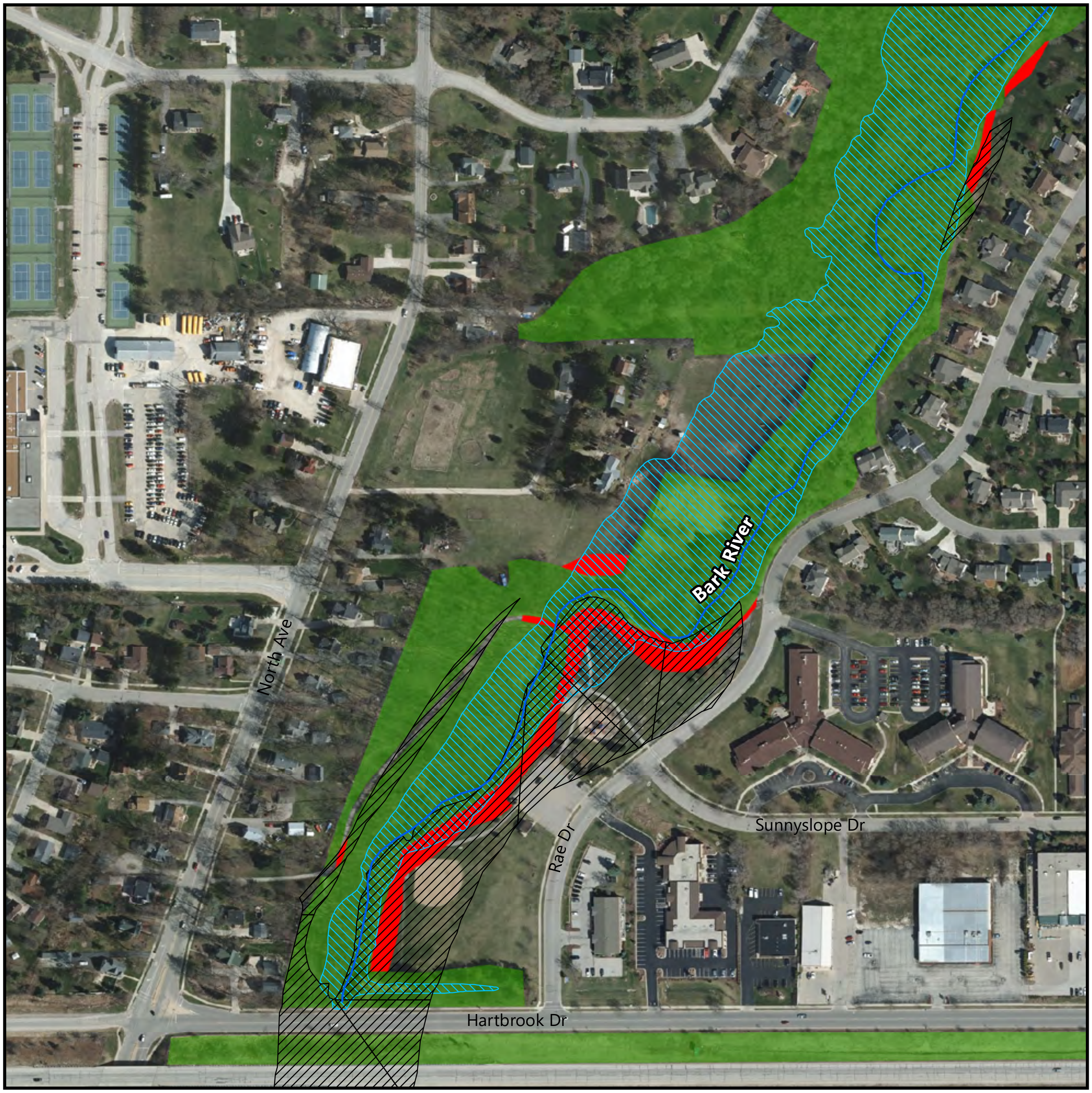
Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 7)
Medium Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 8)
Medium Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



EXISTING RIPARIAN BUFFER:
-PROTECT THESE HIGHEST QUALITY REMAINING HABITAT AREAS.

75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH:
-HIGH PRIORITY TO PROTECT WATER QUALITY AND REDUCE POLLUTANT LOADS.

STREAM
INTERMITTENT STREAM
SURFACE WATER

POTENTIALLY RESTORABLE WETLANDS:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

ONE-PERCENT-ANNUAL-PROBABILITY FLOODPLAIN: FEMA 2015:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

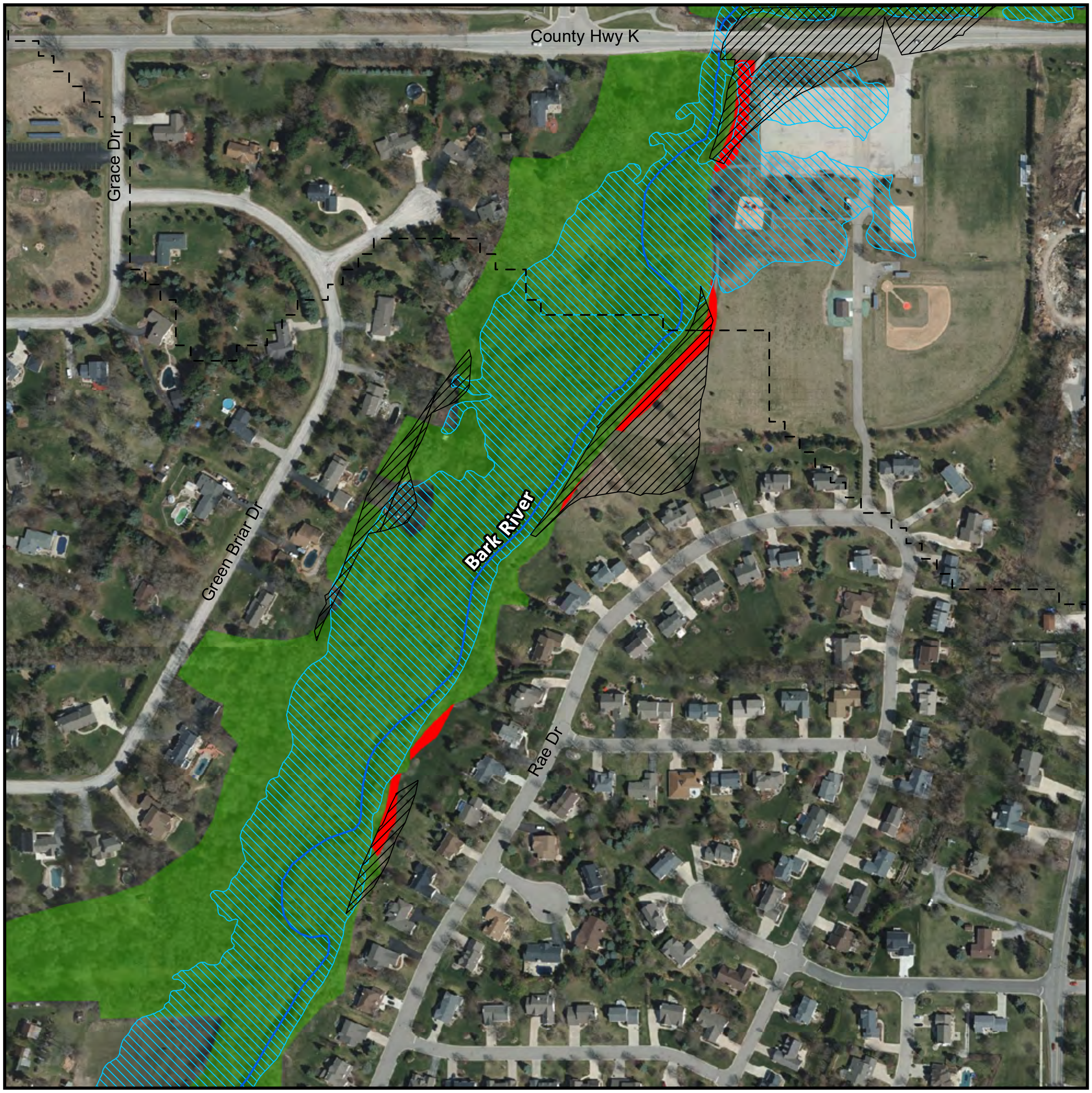
SUB-BASIN BOUNDARIES
WATERSHED BOUNDARY

N

0 150 300 Feet

Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 9)
Medium Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



EXISTING RIPARIAN BUFFER:
-PROTECT THESE HIGHEST QUALITY REMAINING HABITAT AREAS.

75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH:
-HIGH PRIORITY TO PROTECT WATER QUALITY AND REDUCE POLLUTANT LOADS.

POTENTIALLY RESTORABLE WETLANDS:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

ONE-PERCENT-ANNUAL-PROBABILITY FLOODPLAIN: FEMA 2015:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

STREAM

INTERMITTENT STREAM

SURFACE WATER

SUB-BASIN BOUNDARIES

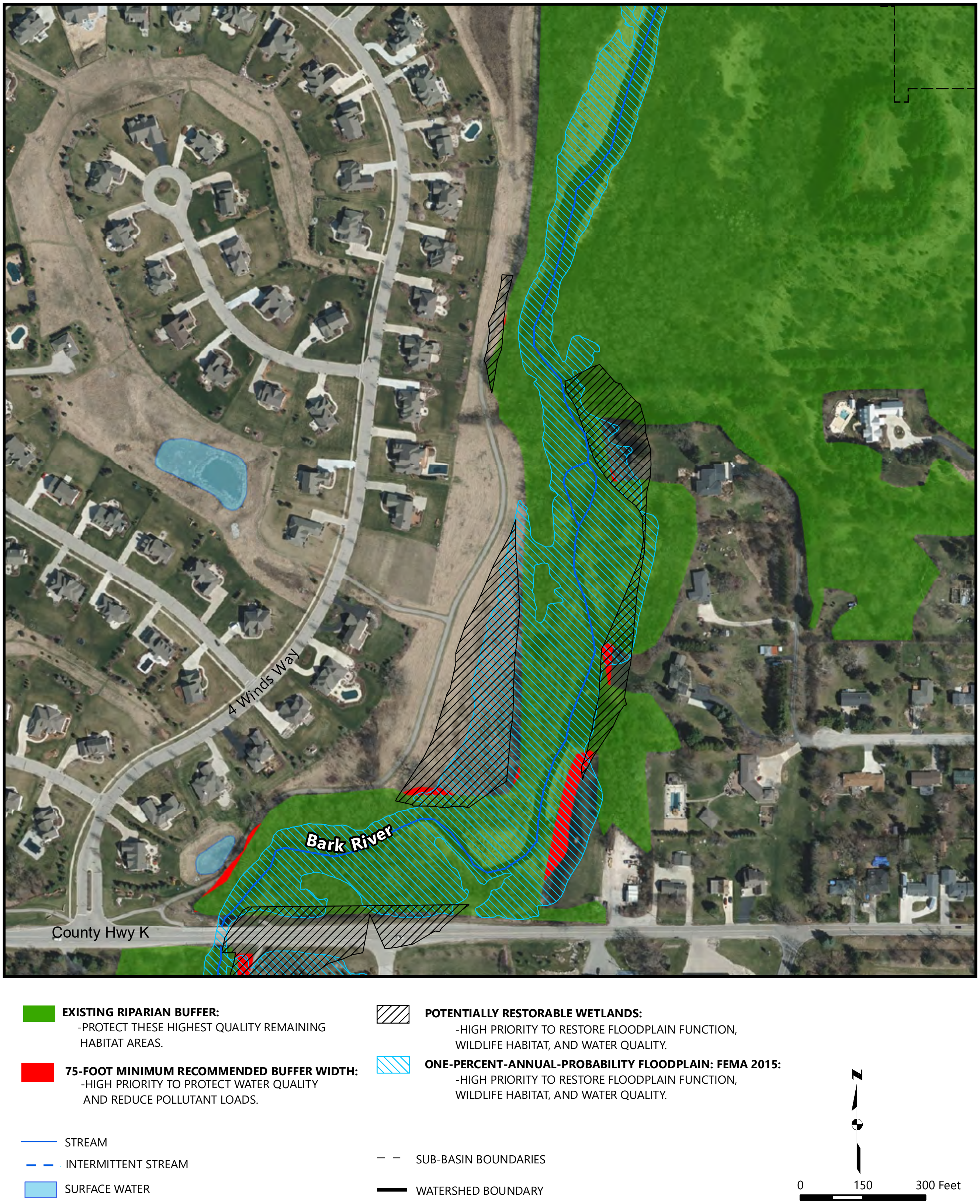
WATERSHED BOUNDARY

N

0 150 300 Feet

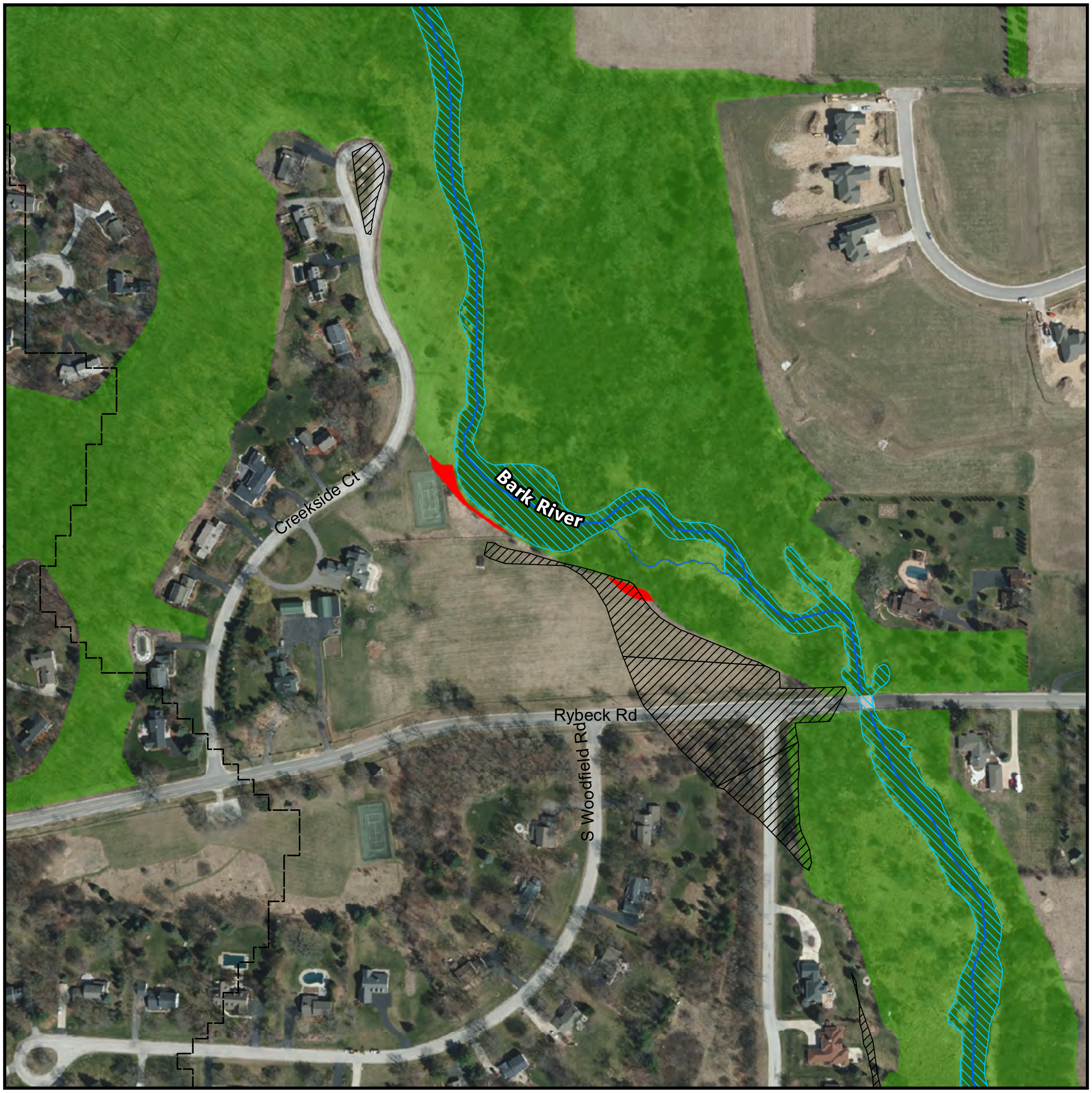
Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 10)
Medium Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 11)
Medium Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



EXISTING RIPARIAN BUFFER:
-PROTECT THESE HIGHEST QUALITY REMAINING HABITAT AREAS.

75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH:
-HIGH PRIORITY TO PROTECT WATER QUALITY AND REDUCE POLLUTANT LOADS.

STREAM

INTERMITTENT STREAM

SURFACE WATER

POTENTIALLY RESTORABLE WETLANDS:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

ONE-PERCENT-ANNUAL-PROBABILITY FLOODPLAIN: FEMA 2015:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

SUB-BASIN BOUNDARIES

WATERSHED BOUNDARY

N

0 150 300 Feet

Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 12)
Medium Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018

EXISTING RIPARIAN BUFFER:
-PROTECT THESE HIGHEST QUALITY REMAINING HABITAT AREAS.

75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH:
-HIGH PRIORITY TO PROTECT WATER QUALITY AND REDUCE POLLUTANT LOADS.

POTENTIALLY RESTORABLE WETLANDS:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

ONE-PERCENT-ANNUAL-PROBABILITY FLOODPLAIN: FEMA 2015:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

STREAM

INTERMITTENT STREAM

SURFACE WATER

SUB-BASIN BOUNDARIES

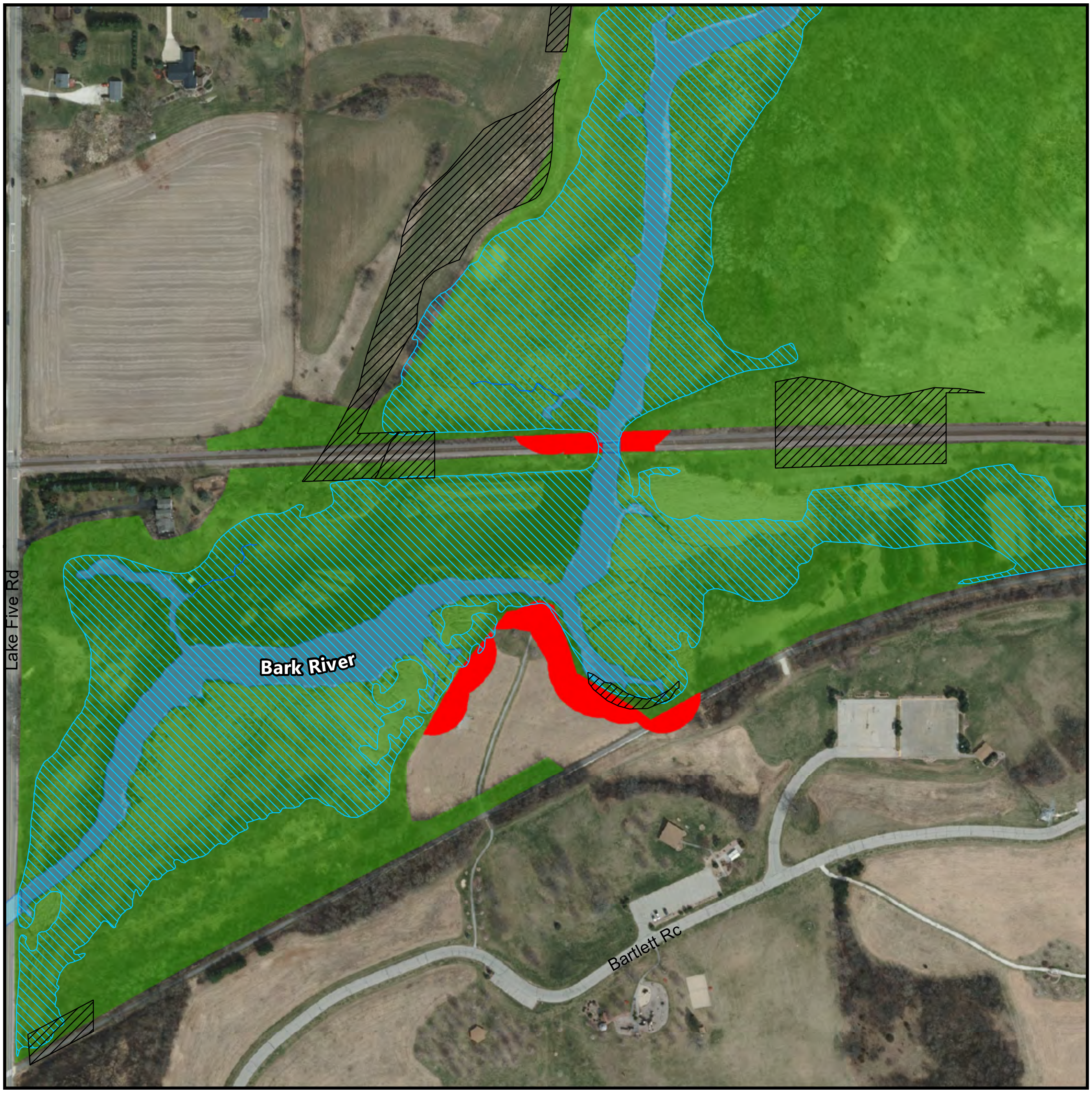
WATERSHED BOUNDARY

N

0 150 300 Feet

Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 13)
Medium Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



EXISTING RIPARIAN BUFFER:
-PROTECT THESE HIGHEST QUALITY REMAINING HABITAT AREAS.

75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH:
-HIGH PRIORITY TO PROTECT WATER QUALITY AND REDUCE POLLUTANT LOADS.

STREAM

INTERMITTENT STREAM

SURFACE WATER

POTENTIALLY RESTORABLE WETLANDS:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

ONE-PERCENT-ANNUAL-PROBABILITY FLOODPLAIN: FEMA 2015:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

SUB-BASIN BOUNDARIES

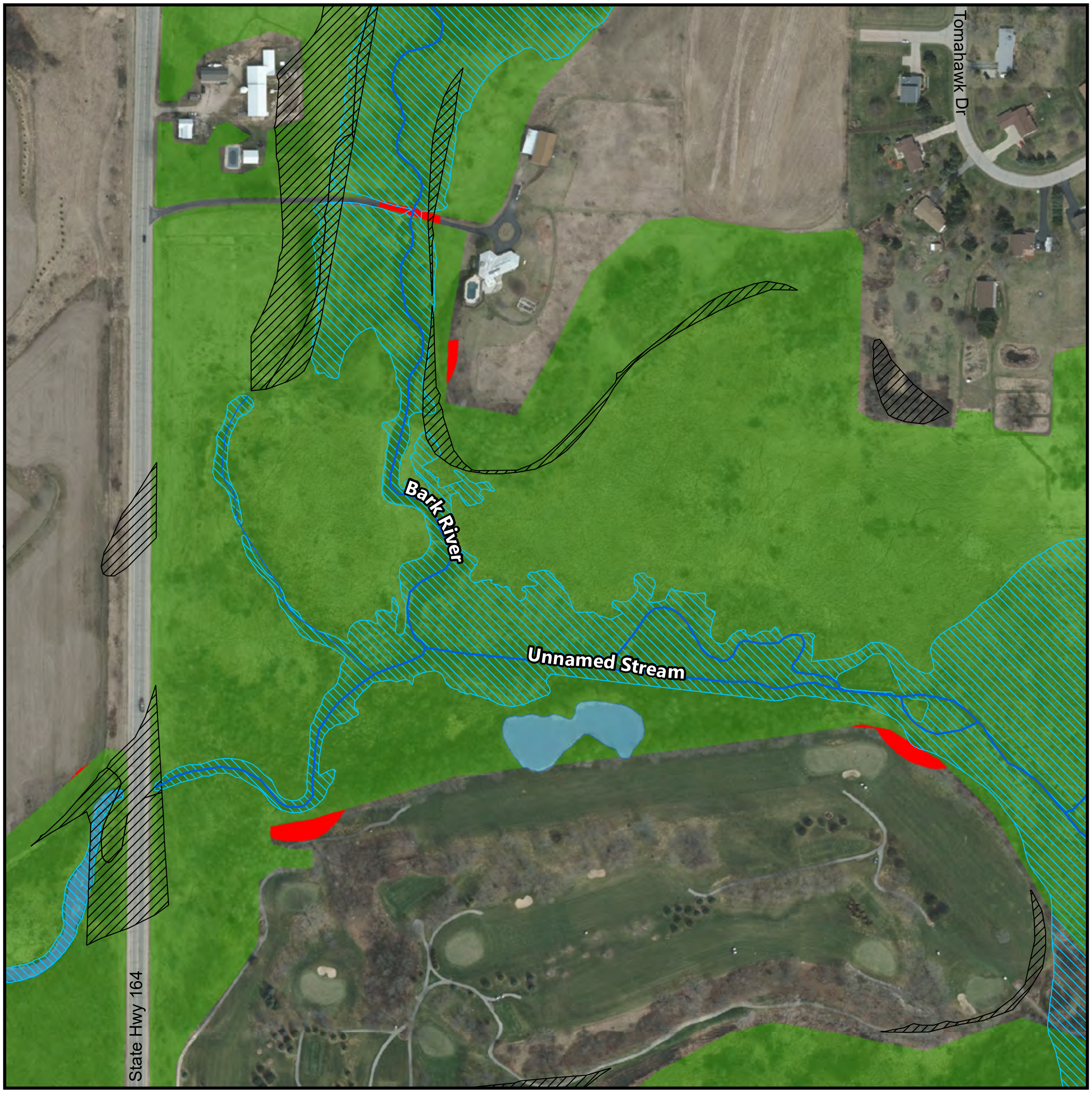
WATERSHED BOUNDARY

N

0 150 300 Feet

Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 14)
Low Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



EXISTING RIPARIAN BUFFER:
-PROTECT THESE HIGHEST QUALITY REMAINING HABITAT AREAS.

75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH:
-HIGH PRIORITY TO PROTECT WATER QUALITY AND REDUCE POLLUTANT LOADS.

STREAM

INTERMITTENT STREAM

SURFACE WATER

POTENTIALLY RESTORABLE WETLANDS:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

ONE-PERCENT-ANNUAL-PROBABILITY FLOODPLAIN: FEMA 2015:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

SUB-BASIN BOUNDARIES

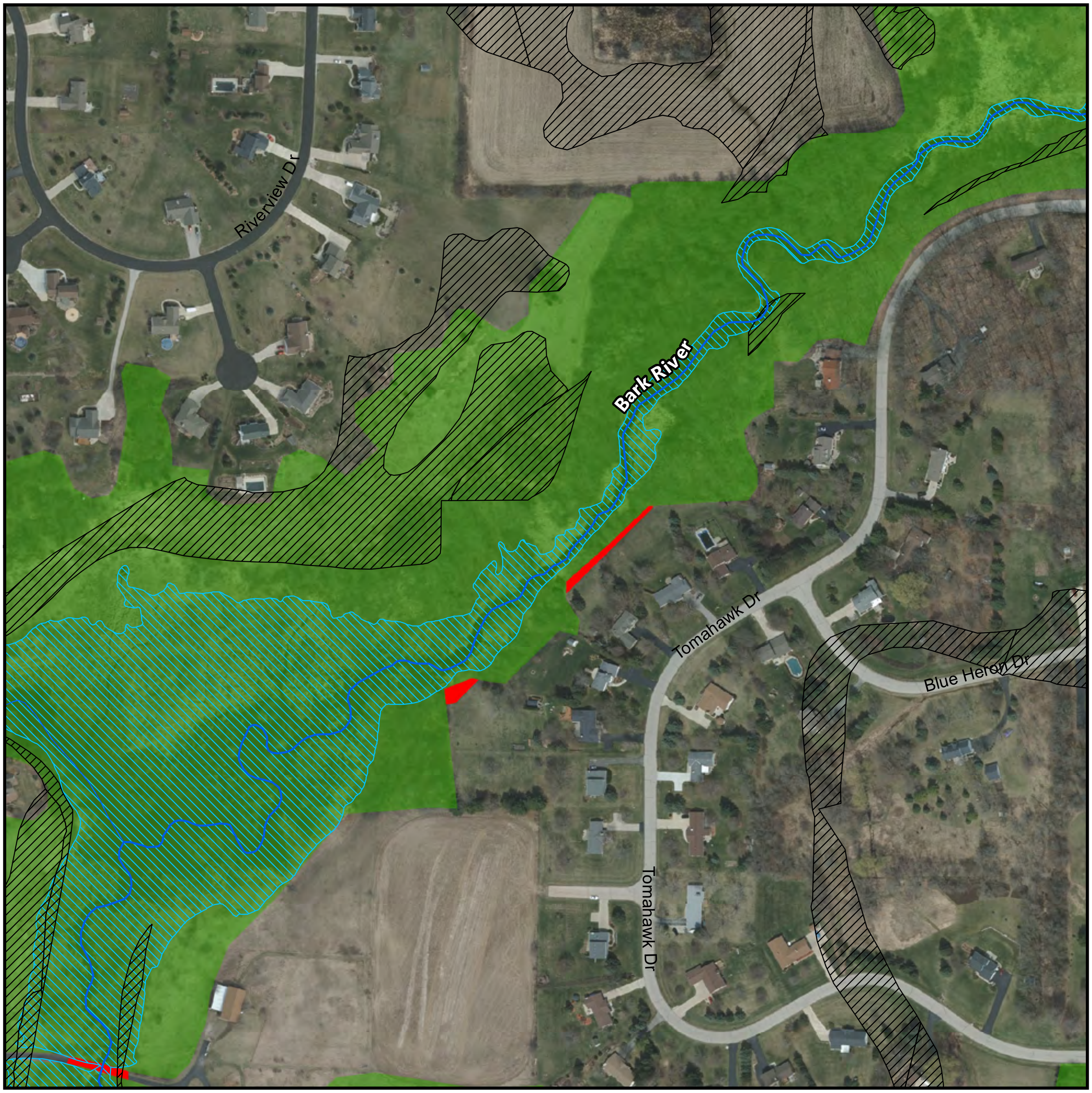
WATERSHED BOUNDARY

N

0 150 300 Feet

Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 15)
Low Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



EXISTING RIPARIAN BUFFER:
-PROTECT THESE HIGHEST QUALITY REMAINING HABITAT AREAS.

75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH:
-HIGH PRIORITY TO PROTECT WATER QUALITY AND REDUCE POLLUTANT LOADS.

STREAM

INTERMITTENT STREAM

SURFACE WATER

POTENTIALLY RESTORABLE WETLANDS:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

ONE-PERCENT-ANNUAL-PROBABILITY FLOODPLAIN: FEMA 2015:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

SUB-BASIN BOUNDARIES

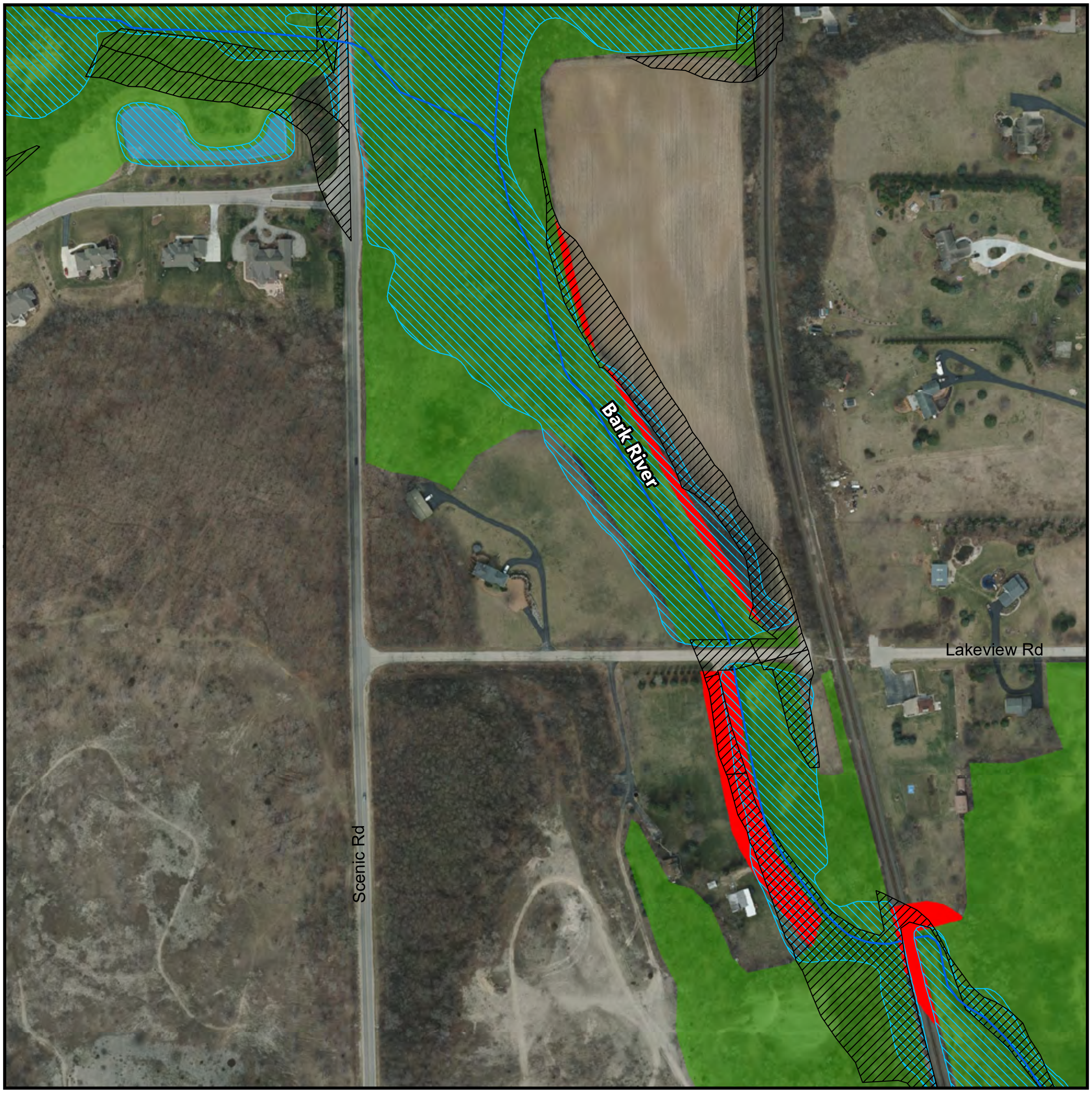
WATERSHED BOUNDARY

N

0 150 300 Feet

Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 16)
Low Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



EXISTING RIPARIAN BUFFER:
-PROTECT THESE HIGHEST QUALITY REMAINING HABITAT AREAS.

75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH:
-HIGH PRIORITY TO PROTECT WATER QUALITY AND REDUCE POLLUTANT LOADS.

POTENTIALLY RESTORABLE WETLANDS:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

ONE-PERCENT-ANNUAL-PROBABILITY FLOODPLAIN: FEMA 2015:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

STREAM

INTERMITTENT STREAM

SURFACE WATER

SUB-BASIN BOUNDARIES

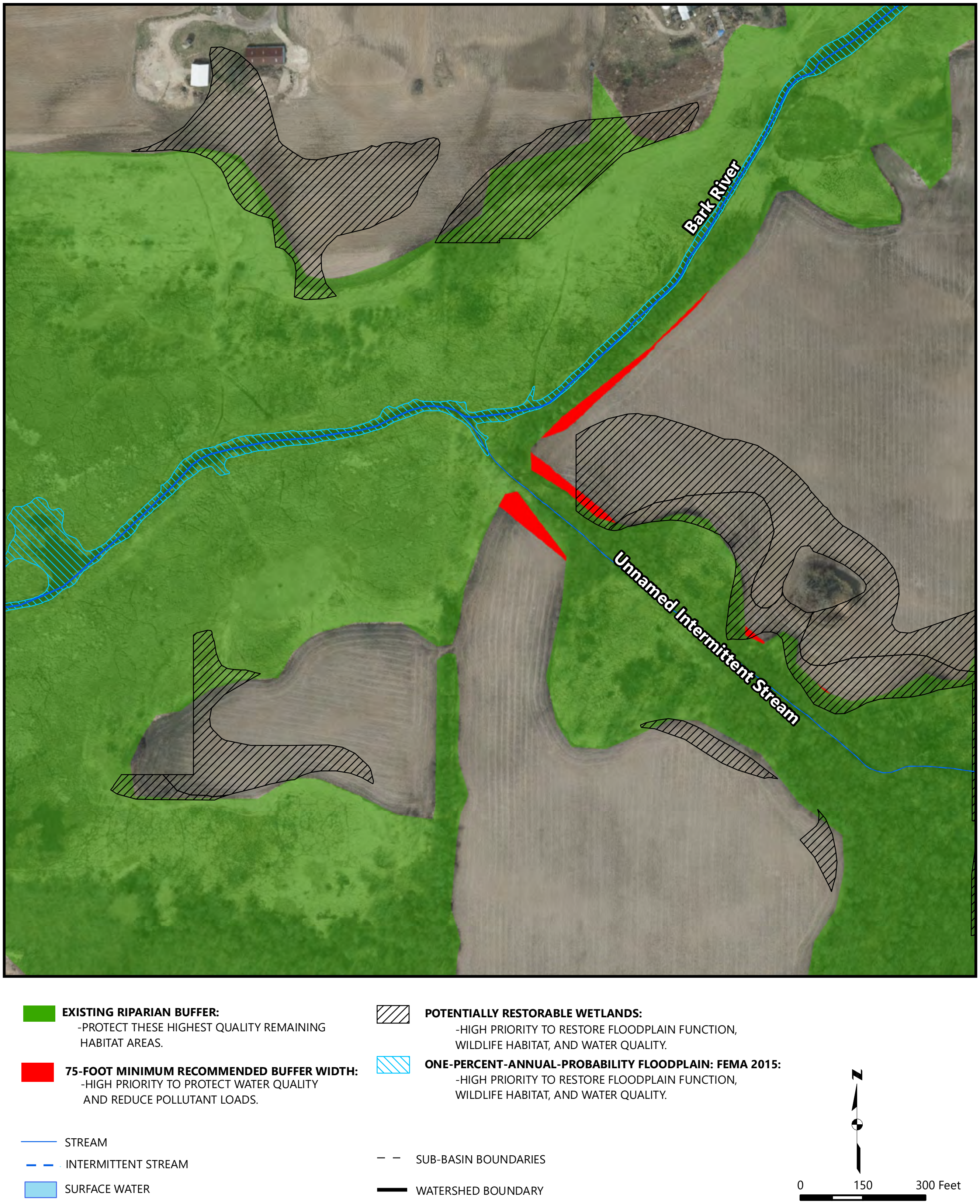
WATERSHED BOUNDARY

N

0 150 300 Feet

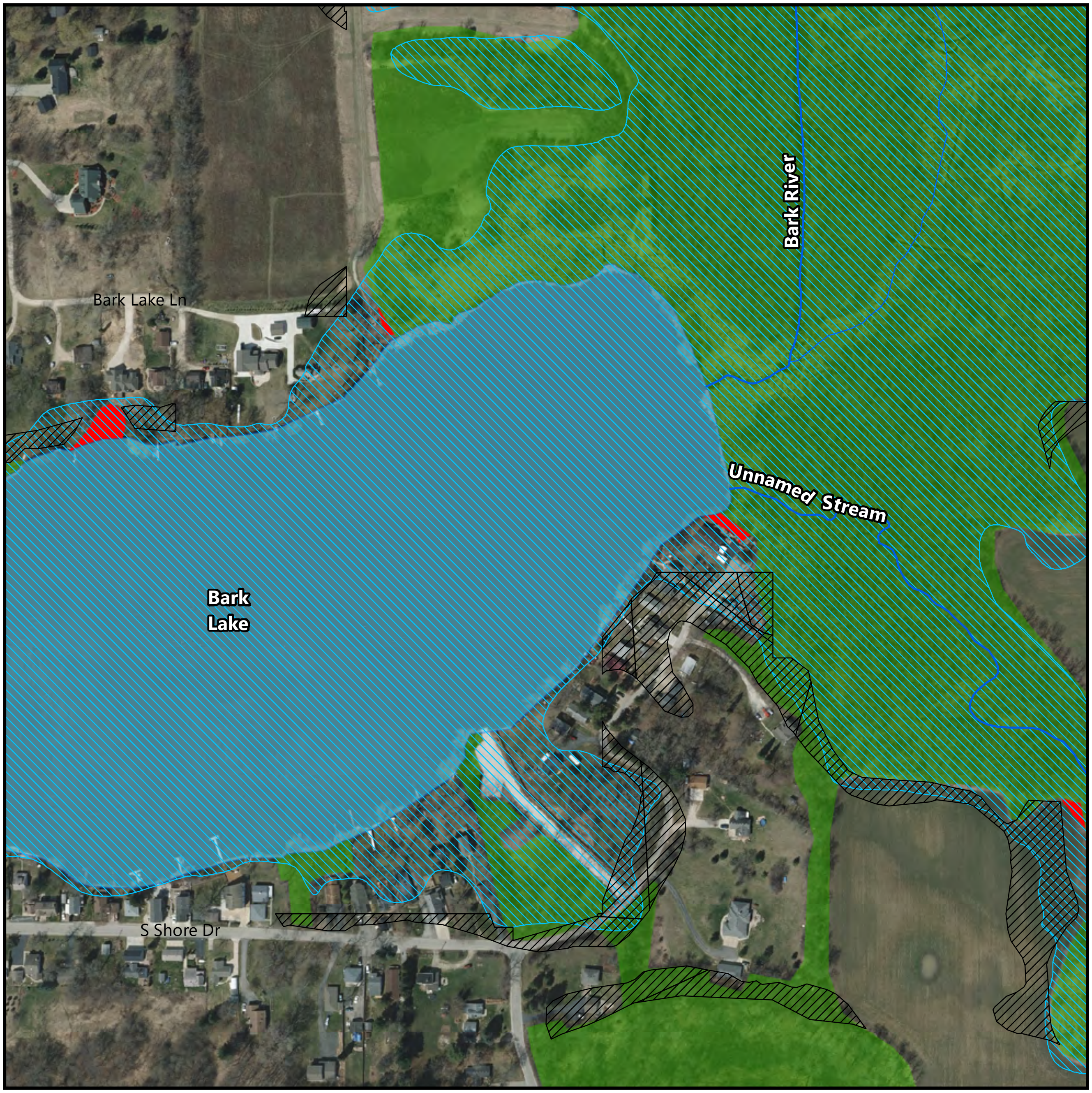
Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 17)
Low Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 18)
Low Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



EXISTING RIPARIAN BUFFER:
-PROTECT THESE HIGHEST QUALITY REMAINING HABITAT AREAS.

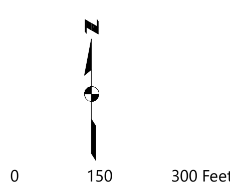
75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH:
-HIGH PRIORITY TO PROTECT WATER QUALITY AND REDUCE POLLUTANT LOADS.

POTENTIALLY RESTORABLE WETLANDS:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

ONE-PERCENT-ANNUAL-PROBABILITY FLOODPLAIN: FEMA 2015:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

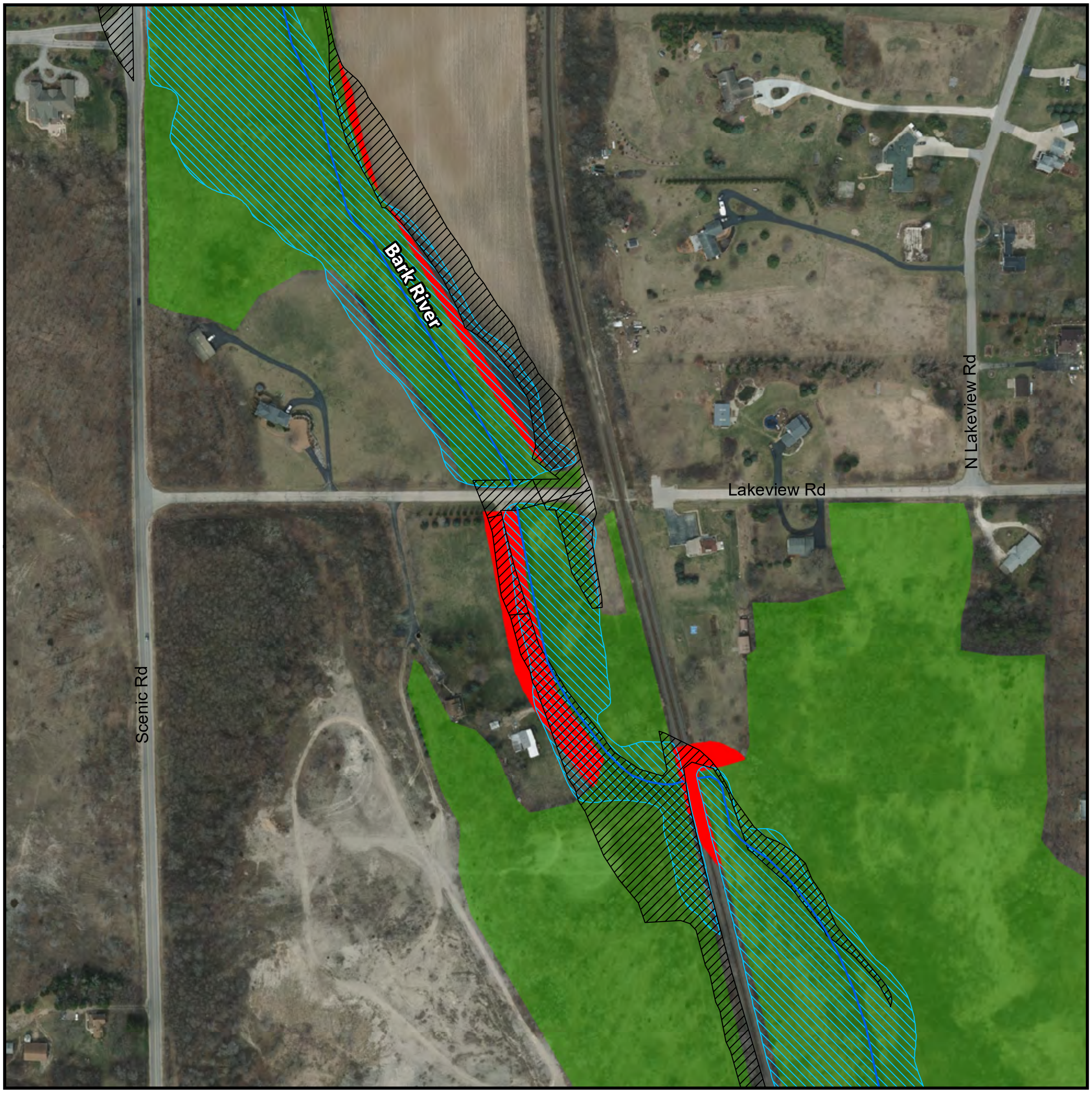
STREAM
INTERMITTENT STREAM
SURFACE WATER

SUB-BASIN BOUNDARIES
WATERSHED BOUNDARY



Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 19)
Low Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



EXISTING RIPARIAN BUFFER:
-PROTECT THESE HIGHEST QUALITY REMAINING HABITAT AREAS.

75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH:
-HIGH PRIORITY TO PROTECT WATER QUALITY AND REDUCE POLLUTANT LOADS.

POTENTIALLY RESTORABLE WETLANDS:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

ONE-PERCENT-ANNUAL-PROBABILITY FLOODPLAIN: FEMA 2015:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

STREAM

INTERMITTENT STREAM

SURFACE WATER

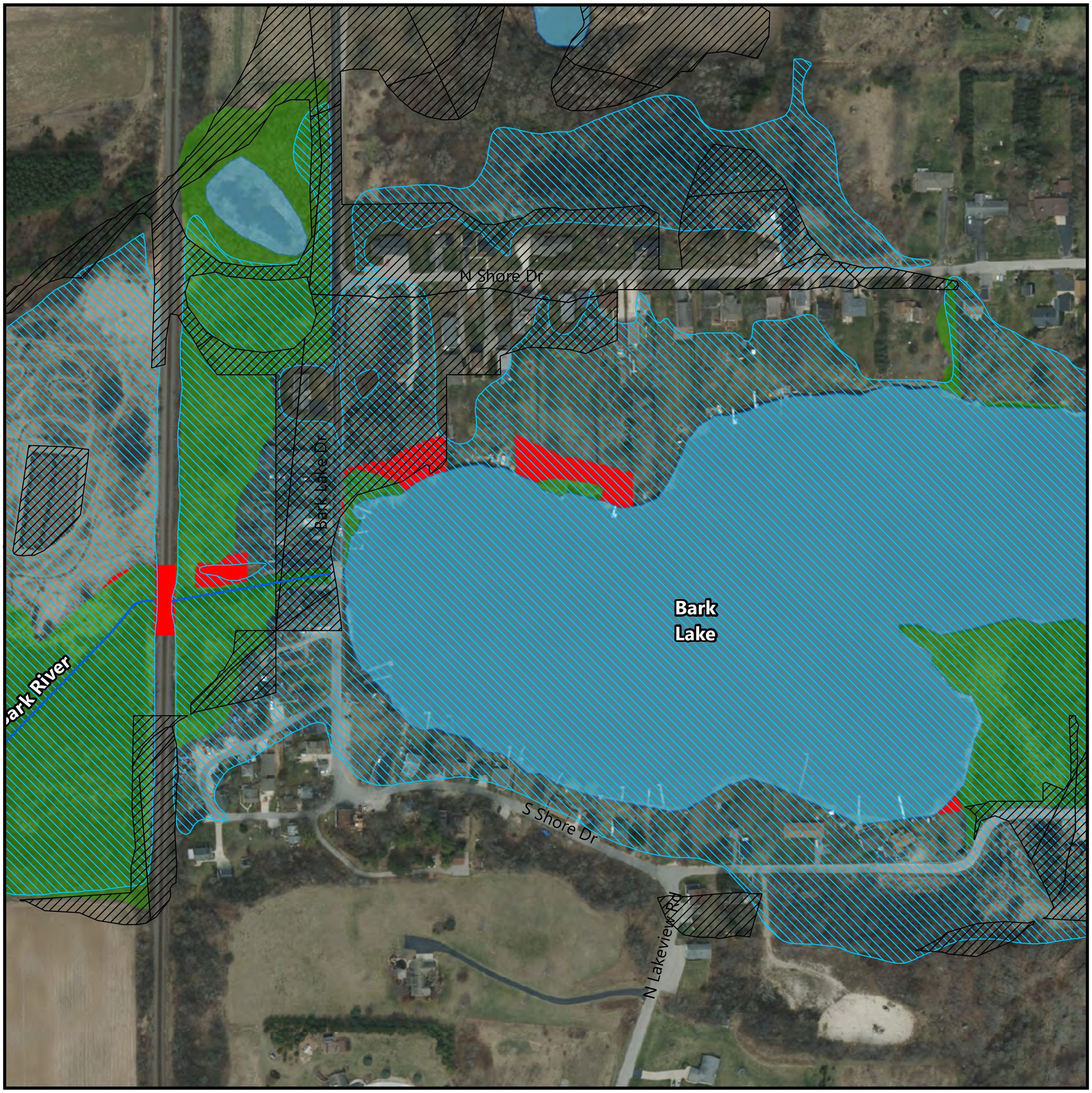
SUB-BASIN BOUNDARIES

WATERSHED BOUNDARY

0 150 300 Feet

Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 20)
Low Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



EXISTING RIPARIAN BUFFER:
-PROTECT THESE HIGHEST QUALITY REMAINING HABITAT AREAS.

75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH:
-HIGH PRIORITY TO PROTECT WATER QUALITY AND REDUCE POLLUTANT LOADS.

POTENTIALLY RESTORABLE WETLANDS:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

ONE-PERCENT-ANNUAL-PROBABILITY FLOODPLAIN: FEMA 2015:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

STREAM

INTERMITTENT STREAM

SURFACE WATER

SUB-BASIN BOUNDARIES

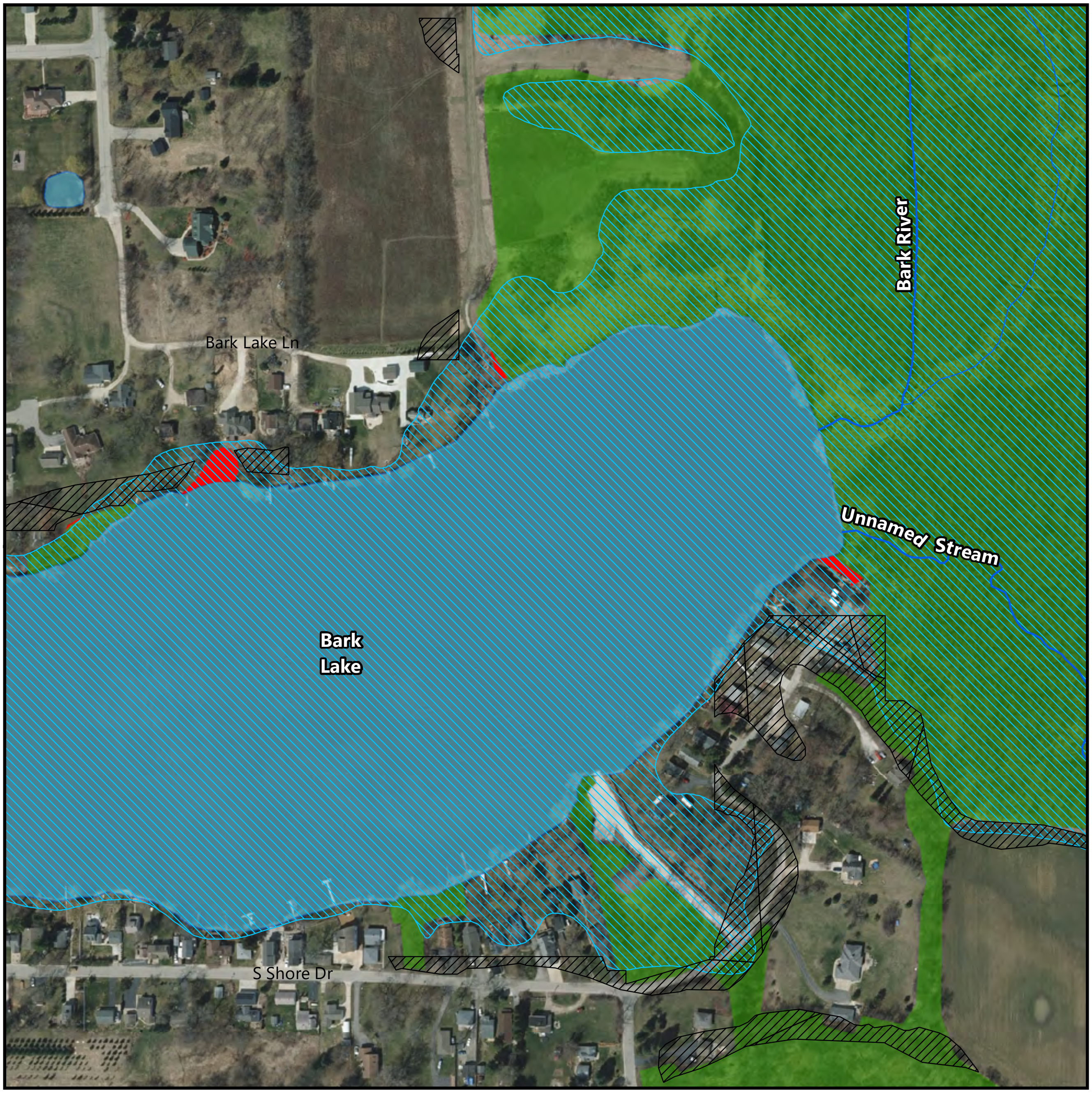
WATERSHED BOUNDARY

N

0 150 300 Feet

Date of Photography: April 2015
Source: SEWRPC

Map F.1 (Inset 21)
Low Priority Riparian Buffer Protection Areas to Improve Water Quality and Wildlife Within the Nagawicka Lake Watershed: 2018



EXISTING RIPARIAN BUFFER:
-PROTECT THESE HIGHEST QUALITY REMAINING HABITAT AREAS.

75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH:
-HIGH PRIORITY TO PROTECT WATER QUALITY AND REDUCE POLLUTANT LOADS.

POTENTIALLY RESTORABLE WETLANDS:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

ONE-PERCENT-ANNUAL-PROBABILITY FLOODPLAIN: FEMA 2015:
-HIGH PRIORITY TO RESTORE FLOODPLAIN FUNCTION, WILDLIFE HABITAT, AND WATER QUALITY.

STREAM

INTERMITTENT STREAM

SURFACE WATER

SUB-BASIN BOUNDARIES

WATERSHED BOUNDARY

N

0 150 300 Feet

Date of Photography: April 2015
Source: SEWRPC

SPECIFICATIONS FOR INLAND LAKE HARVESTERS ILH7-450 AND ILH5-100

APPENDIX G

INLAND
LAKE HARVESTERS

ILH5-100 Aquatic Weed Harvester

Specifications:

Dimensions:	Length Overall..24' (7.31 m)
	Shipping Width..8' (2.43 m)
	Shipping Height...9' (2.74 m)
	Operatingwidth……………………………………………..11.5' (3.51 m)
	Weight...3800lbs. (1587kg)
	Shipping Height Of Harvester On LTR-100 Trailer…….........12' (3.65 m)
Flotation:	Barge Length..16' (4.87 m)
	Barge Width...8' (2.43 m)
	Barge Height...16" (406 mm)
	Watertight Compartments: W/ Poly Floats..14
	Harvester Draft, Empty...6" (152 mm)
HULL:	Construction Options: Mild Steel Sandblasted, Painted, 304 Stainless Steel
Power System &Control Bridge	Engine..Honda Gas Engine
	Hydraulic Pumps...Qty. 2 Hydraulic
	Reservoir ....15 U.S. Gallons (56.78 lt)
	Fuel Tank.. 5 or 6 Gallon Tank
	Hydraulic Controls......................................."Fingertip" Manual Levers
	Power System Controls…………………………Key/Switch, Hour Meter
Harvesting Head	Cutting Width...5' (1.52 m)
	Cutting Depth...4' (1.22 m)
	Belting...SD Galvanized Steel
	Fastenings..........................Adjustable Belt, Tensioners,Stainless Steel
Storage	Maximum Volume..100 Cu. Ft. (2.83 cu.m)
	Weight...1538 Lbs. (698 kg.)
	Belting..SD Galvanized
	Fastenings..........................Adjustable Belt Tensioners, Stainless Steel
Propulsion	Dual Paddle Wheels.................Easily Removable, Hydraulically Driven
Anti-Corrosion	High impact, epoxy with urethane top coat over sandblasted sub-strate. Protection - High Visibility Aqua-Green Or Blue

***Note:** All Specifications Are Subject To Change With Out Notice.*

Inland Lake Harvesters, Inc 1-262-763-3620 www.inlandlakeharvester.com

ILH7-450 Aquatic Weed Harvester

SPECIFICATIONS:

Dimensions:

Length Overall……………………………………………………………40' (12.19m)

Shipping Width…………………………………………………………10'4" (3.16m)

Shipping Height………………………………………………………10' (3.05m)

Weight…………………………………………………………………12,200 lbs. (5533kg)

Hull: Construction……………………………………Mild Steel (Optional Stainless Steel)

Flotation:

Barge Length…………………………………………………………….24’ (7.31m)

Barge Width……………………………………………………………..10’ (3.05m)

Barge Height…………………………………………………………….2’4” (.731 m)

Watertight Compartments…………………………………………..12

Harvester Draft, (empty)……………………………………………..1’ (.304 m)

Harvester Draft, (max load)…………………………………………20” (.508 m)

Barge Protection………………………………….4x4 UV Protected Plastic Runners

Power System & Control Bridge:

Engine…………………………………………… Isuzu diesel w/high temp and low oil pressure shut downs. (Other engines available upon request.)

Paddle Wheel Lifter…………………………………………….Jib Crane Optional

Hydraulic Pump…………………………………………………Pressure Compensated

Hydraulic Reservoir…………………………………………….30 US Gallons (76L)

Systems Capacity………………………………………………..40 US Gallons (114L)

Fuel Tank…………………………………………………………….28 US Gallons (45L)

Bimini Top………………………………………………………………………………….STD

Operator’s Seat…………………………………………………Adjustable w/armrests

Hydraulic Controls…………………………………………”Fingertip” Manual Levers

Power System Controls…………………………………………Full Instrumentation

Harvesting Head: Cutting Width…………………………………………………………………7’ (2.13m)

Cutting Depth……………………………………………………………5.5'-6' (1.65-1.82m)

Horizontal Knives……Reciprocating 3" stroke 3" wide, zinc plated. (75mm)

Vertical Knives………………………………………………Same as above, both sides

Impact Absorption…………………………………………Pivoted Swing Suspension

Belting…………………………………………………………………Stainless Steel Standard

Fastenings……………………………Adjustable Belt Tensioners, Stainless Steel

Two-Stage Storage/Unloading System:

Maximum Volume…………………………………………………450 cu. ft. (12.7cu m)

Maximum Capacity……………………………………………………6921 lbs. (3139kg)

Unloading Height/ Hyd. Adj. up to……………………………………5'6" (1.67m)

Unloading Time……………………………………………………………75-120 Seconds

Belting…………………………………………Heavy Duty, Galvanized w/6 Gage Rods

Fastenings……………………………Adjustable Belt Tensioners, Stainless Steel

Propulsion: Dual Paddle Wheel………………………Easily removable hydraulically driven independently reversible.

Paddle Wheel Diameter…………………………………………………4'4" (1.32m)

Paddle Wheel Width………………………………………………………2'6" (.792 m)

Paddle Wheel Speed…………………………………………………………Variable RPM

Anti-Corrosion System:

High Impact, Epoxy w/urethane top coat over a sandblasted substrate

Protection Color……………………………………………High Visibility Aqua-Green